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VOLUME XII

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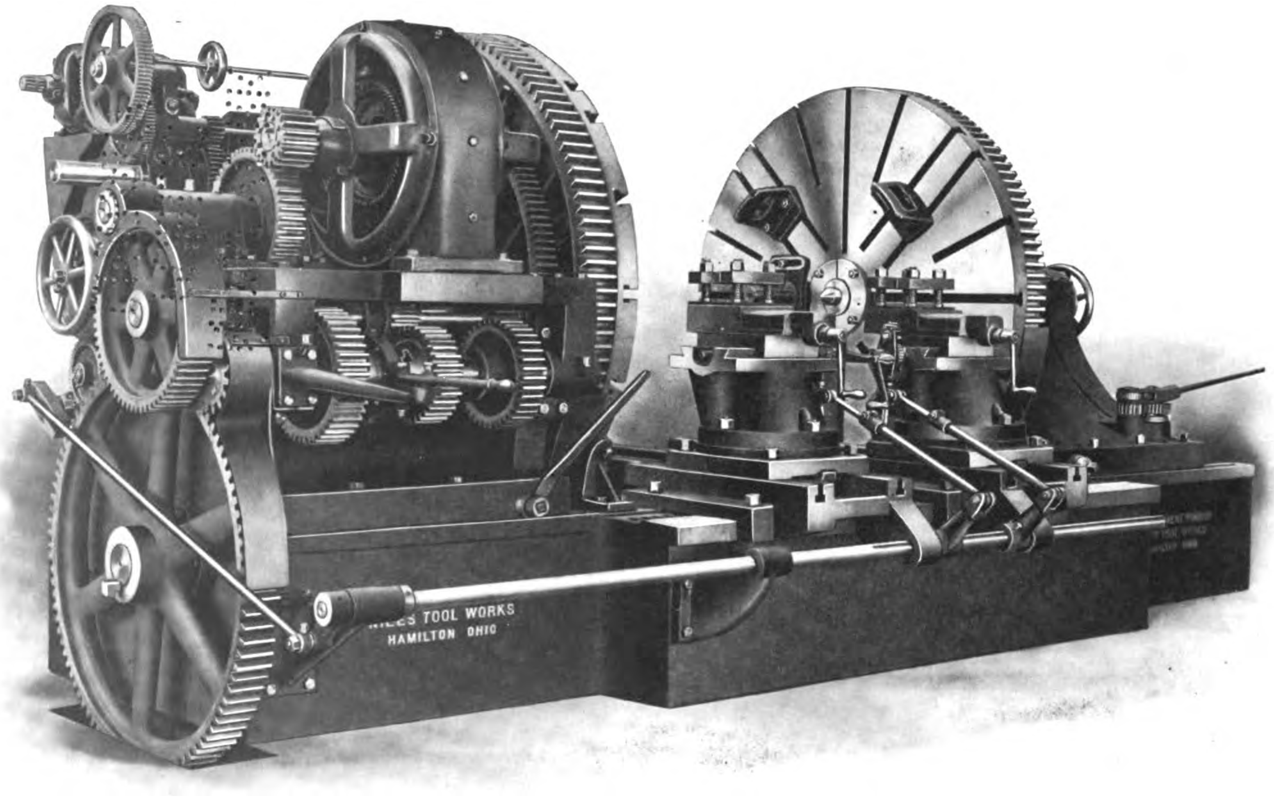
ILES TOOL WORKS
HAMILTON OHIO

84 in. Driving Wheel Lathe Operated by a 25 h.p. CL-B Variable Speed Motor

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PROSPECT AND RETROSPECT

Having survived another financial panic with its deplorable losses but profitable lessons, the country's industries at the threshold of a new year may well look forward to great prosperity. Already, work that was discontinued for lack of funds or lack of confidence has been resumed, and manufacturers in every line see the evidences of renewed activity. Our country is still new and the work to be done in supplying its own needs through the building of roads, working of mines, tilling of soil, and the operation of mills and factories, when judiciously and economically undertaken, offers abundant and profitable opportunities for capital and labor, aside from the further possibilities of commerce with other nations. In all this work electricity is the modern agent of progress—ever itself advancing to new applications, and at the same time furnishing the means for advances in almost every other line.

Incandescent Lighting

Perhaps the most obvious feature of electrical progress during the year just past has been the growing application of the metal filament lamps, particularly the tungsten lamp. Beginning with the comparatively larger units, the only ones available early in the year, there was produced the twenty candle-power, twenty-five watt unit, which is undoubtedly to become a very important factor in indoor illumination. In fact, a growing knowledge of the merits of this lamp and a decrease in the price at which it can be furnished should have a pronounced influence on the spread of electric lighting. When it is borne in mind that the efficiency of light production in the tungsten lamp differs but slightly from what it was in the open carbon arc, the importance of the development of this latest form of metal filament lamp can be easily understood. On the whole, the tendency will be eventually not so much the reduction in the amount of energy consumed for lighting but the increase of the amount of light used or needed. It is a matter for congratulation, too, that the experience with the new form of incandescent lamp shows that it possesses a very satisfactory life and maintains its candle-power at a high percentage of the initial value to the end. The tungsten lamp, originally exceedingly fragile, has during the year been carefully studied, and a considerable improvement may already be noted. For street illumination, especially where the foliage is liable to hamper the distribution from arc lamps, the tungsten lamp, by providing a highly efficient small unit furnishes a means for obtaining a diffused illumination which is likely to be very satisfactory and the extension of which is assured. Meanwhile, the search for substitutes for tungsten of even more satisfactory nature will go on with great activity. Nobody, however, can predict to what practical results this may lead.

Arc Lighting

Naturally, with the improvement in incandescent lights, there has been a great stimulus in the direction of the development of the most highly efficient arc possible. Such development is in a manner forced by the introduction of high efficiency gas mantle lights. At the same time, the close approach to the economy of the open arc by the tungsten incandescent lamp gives a place of greatest importance to those forms of arc in which the flame itself is luminous, and which are known to give efficiencies of light production very largely in excess of those which are obtained with carbon arcs alone. The past year has been noted for great progress in this field, and there is doubtless still room for much advance to be made. We will necessarily, therefore, look forward in the coming year, to many new and interesting results in the arc lighting art. It would seem, indeed, that to the arc in some of its forms, we must look for the final results of maximum candle-power with the minimum energy per candle. Already the gains in this direction have been astonishingly great, and the limit is probably not yet reached.

It may be added that the past year has been characterized by the establishment upon a firm basis of the mercury arc rectifier in series work for converting the alternating currents of the constant current transformer into direct currents for working a series of arcs. At the same time, since it is well known that distribution systems at 25 cycles have hardly been suitable for arc work except through the introduction of motor generator plants, the mercury arc rectifier provides a means for the rectification of these low frequency currents adapting them thereby to arc lighting.

Electrical Distribution

The past year has been characterized by a step forward in electric distribution at high voltages. It has been a moot question as to where the practical limit to the raising of potential on long distance circuits would be found. Doubtless there really exists a practical limit considering such conditions as the preservation of insulation and the freedom from interruptions of service. The fact that distribution service has, during the past year, been inaugurated at potentials in excess of 100,000, puts the question mark, so-to-speak, forward. Experience alone can demonstrate whether, in view of all circumstances, there is any justification for any further great increase in the potential in such distribution. Even in so short a space as ten years the raising of potential and extension of distance of transmission has gone on at a rate that could never have been anticipated at the beginning of the development, and anyone who had the temerity to predict a few years ago that the limit of 100,000 volts would so soon be passed, would have been regarded, to say the least, as somewhat rash in his estimates of future technical growth.

THERMODYNAMICS

Economy is more and more growing to be the watchword in all commercial enterprises. It is forced upon us as an essential to present prosperity and further emphasized by the suggested possibility of exhausting natural resources and leaving future generations destitute. The coal consumed in the United States last year amounted to approximately 450,000,000 tons. It is our duty to devise more economical methods of utilizing the energy in this fuel, and on this account it would be difficult to conceive of a subject of more vital importance at this time than Thermodynamics, and the series of articles by Dr. Steinmetz begun in this number of the Review will undoubtedly be eagerly read by everyone interested in these problems.

In looking over the first installment, the reader will be impressed with the thoroughness with which the subject is attacked. In his characteristic way, Dr. Steinmetz first derives the general laws applying to the subject; he then deduces those laws of thermodynamics that have formerly been empirical, and shows that they can be theoretically proved by simply assuming the law of central forces, the law of gravitation, and that heat energy is the energy of irregular motion.

In the lectures following, Dr. Steinmetz discusses the Carnot Cycle and proves that while it is theoretically the most efficient, due to practical limitations it is by no means the best cycle to use. He shows what efficiencies are to be expected in the steam cycle as well as the various cycles of gas and other heat engines, and finally ends the lectures by a numerical application of the equations to the practical design of a steam turbine.

ELECTRICALLY OPERATED FIRE-BOATS

The first fire-boats to be propelled by electric power have recently been completed at the Manitowoc Dry Dock Company. An article by Mr. Charles C. West, appearing in the present issue, gives an account of the pumping test, and a brief statement of the results obtained from the electric propulsion.

Prominent among the advantages secured by this method of propulsion are very complete and simple control, and the replacing of a pair of reciprocating engines by apparatus requiring less attention and less space.

The former feature is considered particularly advantageous in a fire-boat, as everything can be controlled from the pilot house, and the boat can be held in any suitable position without the delay necessarily occasioned by signals.

GENERAL ELECTRIC REVIEW

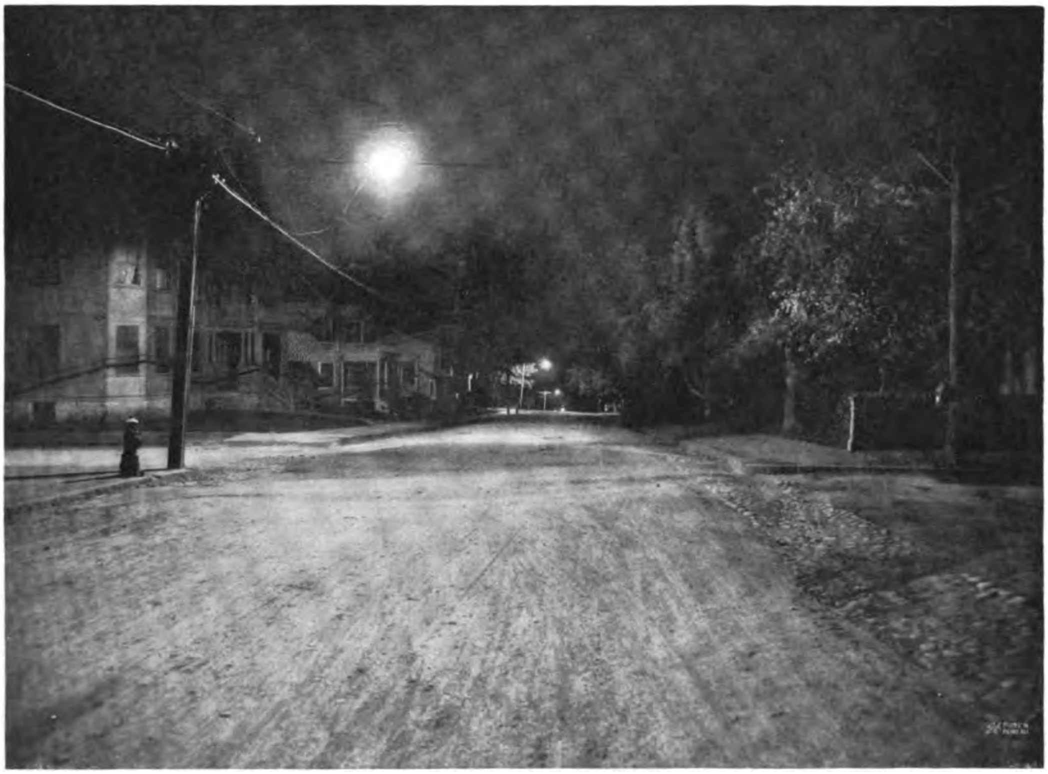
With the opening of the new year the Review begins another new volume—the twelfth since its establishment—and takes this opportunity to express its cordial appreciation of the invaluable support of its many friends. The reception accorded the Review has been more than gratifying, because of the confidence expressed and because it indicates a measure of success in the accomplishment of the purposes for which the paper was founded.

A COMPARISON OF PRESENT DAY METHODS OF STREET ILLUMINATION

By N. R. Birge

In view of the thousands of dollars annually spent in our cities for public improvements, it is surprising to note in how many instances the public lighting is left to remain as it was a decade ago. These antiquated methods of illumination are not only unprofitable to the stations operating them, but fail to give the public the benefit of the advantages to be derived from the more modern illuminants. When arranged in accordance with present day practice, the later lighting equipments not only provide for the quantity and quality of the illuminants required, but for their esthetic arrangement as well.

In considering the most desirable method of illumination, one must be governed by local conditions, as the amount of illumination required varies in accordance with the locality. For districts requiring a high degree of illumination, the arc lamp is best adapted. On the other hand, there are districts where the volume of light from the arc is more than is required, or more than can be used effectively, as, for example, where the presence of dense foliage confines the illumination from any one source to a very restricted area. For such localities the series incandescent lamp can be used to advantage. With a combination of arc and incandescent lights the esthetic results are not only enhanced but an increase in revenue to the operating station is realized. Many incandescent lamps will therefore be added to the circuits of the lighting company in districts that have formerly been left in total darkness on account of the lack of satisfactory and



Street Illuminated by Luminous Arc Lamps, Fall River, Mass.

inexpensive units of low illuminating intensity.

In the early days of arc lighting the open carbon arc was such a pronounced improvement over the illuminants then in general use that the details of cost and maintenance were not seriously considered. The advent of the enclosed arc lamp, however, opened up a new field, and since the days of its introduction there has been a steady improvement in its mechanical construction and the quantity and quality of its illumination, with a resulting economy in operation.

General Electric Luminous Arc Lamp

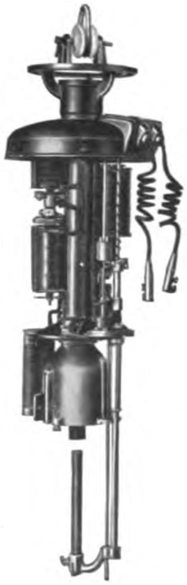
In endeavoring to further increase the illuminating efficiency of the arc lamp, at the same time maintaining its simplicity of construction, it became necessary to abandon the use of carbon electrodes for those composed of other substances. This resulted in the adoption and perfection of the "magnetite," or "luminous arc," as most suitable to meet present requirements.

When designing the mechanism of the luminous arc lamp, the most important details to be considered were the method of feeding the electrodes, and their relative positions. Naturally, the first step towards perfecting these important details embodied methods most commonly employed in connection with the carbon arc; *viz.*, a clutch mechanism acting directly upon a composition electrode arranged to feed in a downward direction.

On account of the peculiar characteristics of the arc, this method introduced complications of such a serious nature that it was abandoned for a simpler construction, which not only overcomes the mechanical difficulties formerly encountered but embraces the advantages derived from the ideal distribution of light rays from the arc. The design has been perfected to such a high degree that more than 25,000 luminous arc lamps are now in successful commercial operation, with results most gratifying to both the general public and the operating stations.

The luminous lamp commends itself to operating managers for the following reasons:

First. The lamp consumes only 310 watts and gives 30 per cent. more effective illumination than is secured with a 480 watt carbon lamp.



Luminous Arc Lamp, Casing Removed

Second. Electrodes have a life of 175 to 200 hours; consequently, the cost of trimming is lower.

Third. No enclosing globes are required, thus eliminating this item of maintenance.

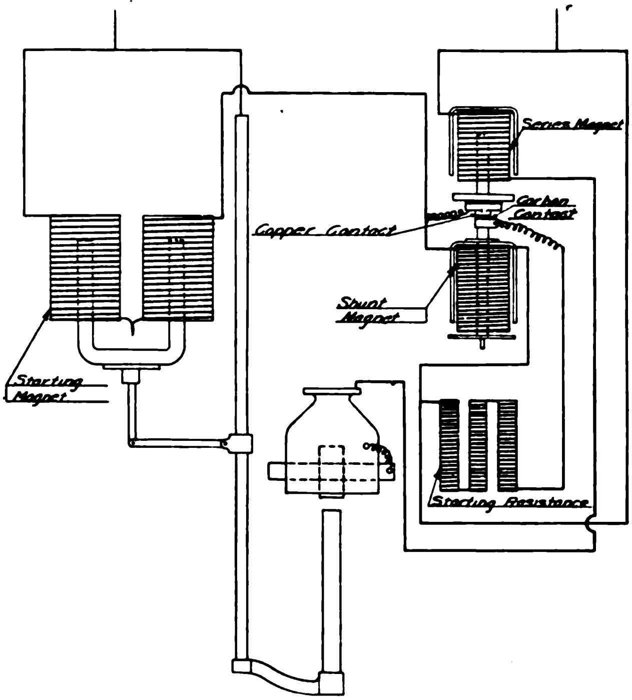
Fourth. Ideal distribution of light due to the permanent position and character of the arc.

The proper wattage consistent with suitable illumination, with due respect to low operating and maintenance expense, was determined from actual experience, and a current consumption of 4.0 amperes and an arc voltage of 75 was decided upon. A higher or lower adjustment, however, can readily be made, either at the operating station or at the place of manufacture.

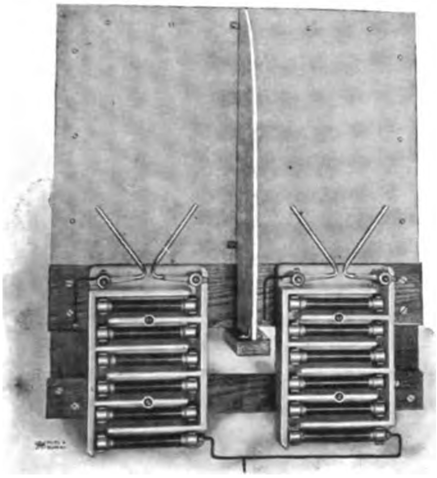
Although designed primarily for operation on 4 ampere direct current circuits, the luminous arc lamp can be operated with equal success from an alternating current source by means of a motor generator set or a suitable current rectifier.

The motor generator set, consisting of an alternating current motor driving a direct current series arc machine, is familiar to all operating engineers.

The current rectifier, commonly designated as the series mercury arc rectifier, includes a constant current transformer, series mercury arc rectifier tube, tank for tube, transformer for exciting rectifier tube, and switchboard.



Connections of Luminous Arc Lamp



Horn Type Lightning Arrester

The constant current transformer used with this outfit has the same characteristics as the one used with the well-known series alternating arc systems. The primary windings are connected to a constant potential alternating current supply of any commercial voltage or frequency. The secondary windings are connected to the anodes, or alternating current terminals of the rectifier tube. A tap in the middle of the secondary winding connects the transformer and its direct current reactance to the negative end of the lamp circuit; the positive end of the lamp circuit being connected through an ammeter to the cathode of the rectifier tube.

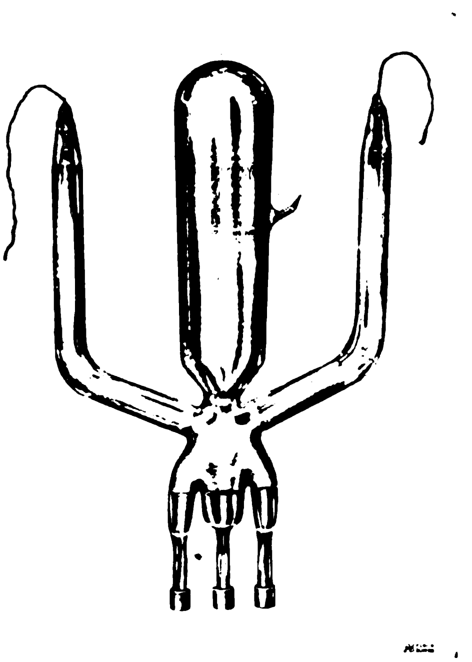
The adjustment for the proper current in the lighting circuit is obtained by changing the weights attached to the rocker arm which supports the movable coil of the transformer.

The rectifier tube, by means of which the alternating current is transformed into direct current, consists of an exhausted glass vessel, enclosed in a steel tank filled with oil; the oil being maintained at the proper temperature by means of water cooling coils.

The exciting transformer is used to supply a low potential current to the starting anodes and cathode of the rectifier tube.

The standard series rectifier switchboard consists of blue Vermont marble supported on a pipe frame, the bottom of the panel being above the floor level. The equipment consists of the necessary instruments and switches for the control of the circuit.

Until recently, low frequency alternating current circuits (25 to 30 cycles), without motor generator or frequency changing sets, have been used very little for arc lighting purposes.



Mercury Rectifier Tube

However, the rectifier set, which fulfills the purpose of the motor-generator, can be operated at these low frequencies. The first cost of the rectifier set is much lower than that of a motor-generator or frequency changer, the efficiency is higher, and less floor space is required.

The following is a comparison, showing the costs of operating a one hundred light open arc system and a one hundred light series luminous arc rectifier system. In making this comparison, three distinct problems are considered:

First. Interest and depreciation on the investment.

Second. Maintenance, including cost of electrode renewals, trimming and repairs.

Third. Cost of energy consumed.

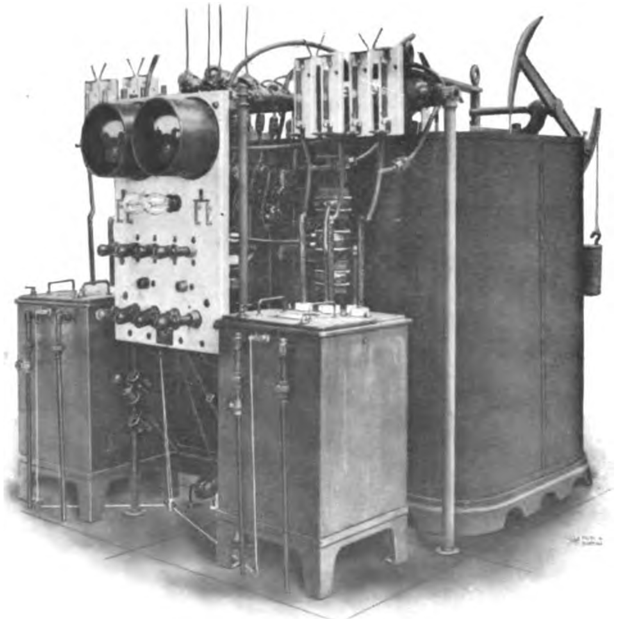
INTEREST AND DEPRECIATION ACCOUNT

	Open Arc	Luminous Arc Rectifier
Approximate scrap value of 100-light, 9.6 ampere A.C. Open Arc System, including belt driven arc machine, lamps and cutouts	$600.00	
Cost of 100-light Luminous Arc Rectifier System, complete with lamps, cutouts, etc., and including generator capacity .		$5700.00
Interest and depreciation at 12 per cent. per annum . . .	72.00	684.00

The cost of the distributing lines has been omitted, as this would be the same for either system.

MAINTENANCE

Trimming	Open Arc	Luminous Arc Rectifier
Open arcs are trimmed every day. One man at $50. per month can trim 100 lamps per day, making cost per lamp per year .	$6.00	
Luminous arcs are trimmed about 23 times per year of 4000 hours. One hundred lamps would require about ⅙ of a man's time, making cost per lamp per year		$1.00



100-Light Outfit for Luminous Arc Lamps

	Open Arc	Luminous Arc Rectifier
Carbons and Electrodes		
Open arcs require two carbons per day, or 730 per year, at a cost of $7.50 per 1000. Cost per lamp per year . . .	5.50	
The luminous arcs require trimming of the lower electrode every 175 to 200 hours, or 23 times per year; the upper electrode every 4000 to 6000 hours. Cost of lower electrodes, 5 cents each, and upper electrodes, 55 cents each, making the cost per lamp per year		1.70
Outer Globes		
A fair allowance would be 30 cents per lamp per year for the open arcs, and 50 cents per lamp per year for the luminous arcs .	.30	.50
Repairs		
This item is difficult to determine on account of varying local conditions, but a conservative estimate based on an average figure would be	2.50	.75
Tube Renewals		
Cost of tube renewals, based on average central station reports, would not be more per lamp per year than		3.00
Total maintenance charge per lamp per year	14.30	6.95
Total for 100 lamps . . .	1430.00	695.00

COST OF ENERGY

The line loss in each installation will depend on the length of line, but for the purpose of comparison a loss of 10 per cent. at 9.6 amperes is taken as a representative case. Assuming the size of wire to be the same for both systems, the relative losses will be proportionate to the square of the current.

	Open Arc	Luminous Arc Rectifier
Watts consumed at terminals	480 watts	310 watts
With a line loss of 10 per cent. and a generator efficiency of 64 per cent. each 9.6 ampere open arc lamp requires 835 watts at the engine shaft, or a total for the system of .	83,500 watts	
With a line loss of 2 per cent. and a generator and transformer efficiency of 83 per cent., each 4 ampere luminous arc lamp requires 380 watts at the engine shaft, or a total for the system of . .		38,000 watts

	Open Arc	Luminous Arc Rectifier
Burning 4000 hours per year, with the cost of energy at 1¼ cent per kilowatt hour, the cost per lamp per year would be	$50.10	$22.80
Total for the system .	$5010.00	$2280.00

SUMMARY

	Open Arc	Luminous Arc Rectifier
Interest and depreciation .	$ 72.00	$ 684.00
Maintenance	1430.00	695.00
Energy	5010.00	2280.00
Total for 100-light system .	$6512.00	$3659.00

This shows an annual saving in favor of the luminous arc rectifier system of $28.53 per lamp, or a total saving per year of $2853.00.

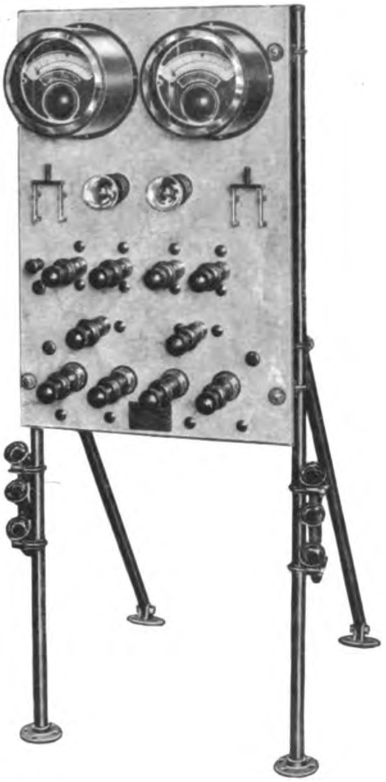
ARC CUTOUT
GENERAL ELECTRIC CO.
U.S.A.

Form H Cutout

Therefore, the total net investment of $5,700.00 for the luminous arc rectifier system will be paid for in about two years, after which the net annual saving will create a dividend of more than 50 per cent. on the new investment.

Parallel with the improvement of series arc lamp efficiency, rapid progress was made in the development of the series incandescent lamp. The first series incandescent lamps were placed in service in 1880, and were operated in series with open arcs supplied from arc dynamos, but these incandescents were crude, inefficient and short lived.

It was about fifteen years later that the manufacturers realized that to improve the operation of these lamps and produce a satisfactory system for street lighting, the development of a suitable regulating device was essential. During this period the bank board system was first introduced. This was followed by the shunt box method of regulation, and still later by the reactive coil; but it was not until 1902 that the constant current transformer was commercially introduced as a means of regulation.



Switchboard for 100-Light Circuit

The advantages of the constant current transformer over other methods of regulation are:

First. The absence of a grounded secondary or circuit line.

Second. Since the life of the lamps depends largely on the regulation of the lighting system, the close regulation of the constant current transformer reduces lamp renewals to a minimum.

Third. The constant current transformer, which combines the step-up transformer and reactive coil, avoids the necessity of two separate pieces of apparatus and reduces the amount of floor space required.

Some of the old systems mentioned still occasionally enter into competition with the constant current transformer because of a slightly lower initial cost of installation. They lack, however, many of the essential features necessary for an efficient installation, the most important of these being close regulation. Past experience has proved that with each improvement in regulating apparatus, a corresponding improvement in the life of the incandescent lamps has resulted.

The first series incandescent lamps were of an efficiency of about 5 watts per candle. Improvements in lamp manufacture produced a 4 watts per candle lamp, and later a 3.5 watts per candle lamp giving better life results; and only a few years ago the GEM metallized filament lamp was introduced, with an efficiency of 2.7 watts per candle. The introduction of the tungsten lamp has been the latest step in advance, giving us a lamp of 1¼ watts per candle, which efficiency is maintained practically constant throughout a life of from twelve hundred to fifteen hundred hours.

The following is a comparison, showing the cost of operating one hundred 40-candle-power carbon filament, GEM filament, and tungsten incandescent lamps.

Cost of Energy

The carbon filament lamps are assumed to have an efficiency of 3½ watts per candle-power; the GEM filament lamps, 2.7 watts per candle-power; and the tungsten lamps, 1¼ watts per candle-power. Assuming that the lamps burn 4000 hours per year, and that the energy costs 1½ cents per kilowatt hour, the cost for 100 lamps would be:

Carbon filament lamp	$840.00
Gem filament lamp	648.00
Tungsten lamp	300.00

(These figures do not include loss in transformer or generator.)

Cost of Renewals

	Carbon	Gem	Tungsten
Number of renewals	4	4	3
Price of lamp	$ 0.493	$ 0.553	$ 1.215
Cost of renewals per 100 lamps	197.20	221.00	364.50

The total cost of 100 lamps, including energy and renewals, would be:

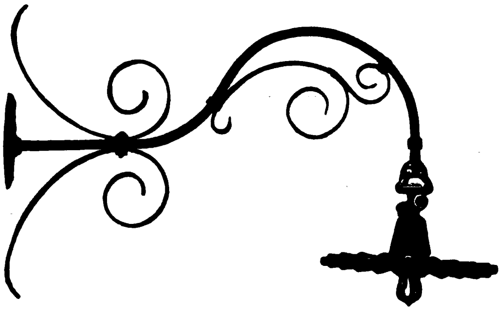
Carbon filament lamp	$1037.20
Gem filament lamp	869.00
Tungsten lamp	664.50

The saving in favor of the tungsten lamp would therefore be:

Tungsten over Gem	$204.50, or $2.05 per lamp per year
Tungsten over Carbon	372.00, or 3.73 per lamp per year

The station equipment for any series incandescent system may be a part of the series arc lighting outfit previously described, with the lamps in series with the luminous arc lamps; or it may be entirely separate. The former arrangement is generally the one employed in large towns and cities where both arcs and incandescents are used, and the latter in smaller places where only the incandescents are required.

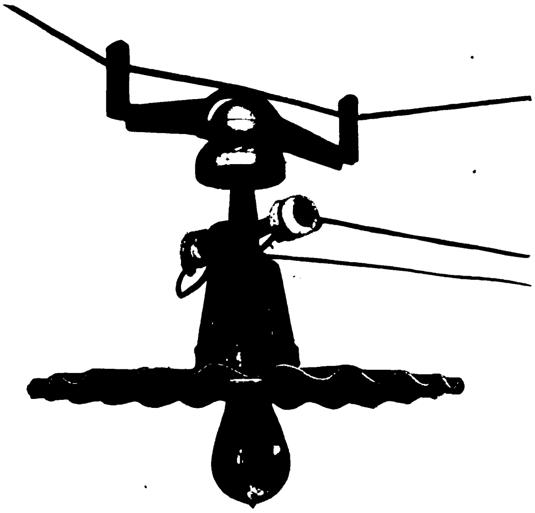
For installations consisting entirely of incandescent units, the constant current transformer has been standardized for a primary voltage of 1100 or 2200 volts, and frequencies of from 60 to 125 cycles, in capacities of 4, 8, 16, 22 and 32 kilowatts. Special transformers, however, can be built for almost any primary voltage, frequency or kilowatt output. The standard secondary or line current adjustments are for 3.5, 4, 5.5 and 6.6 amperes, although 1.75 and 7.5 ampere transformer can be furnished if desired.



Street Bracket and Radial Wave Reflector

Tungsten lamps have been designed for 25, 32, 40 and 60 candle-power, for standard current adjustments. In addition, higher candle-power lamps are being developed, and may possibly be had in the near future, in sizes of 80, 100 and 200 candle-power.

Various arrangements for the suspension of these small units have been perfected, the latest and most popular of which is the ornamental bracket fitted with a radial reflector. This reflector serves the double function of protecting the lamp and of directing the rays in the most efficient



Center Span Fixture

direction, thus increasing the effective illumination about 20 per cent. The brackets are mounted on poles placed on alternate sides of the street at equal distances apart, and so arranged that the lamp is suspended about four feet out from the curb. The proper height of the suspension depends on the intrinsic brilliancy of the illuminating unit, the distance between the poles, and the necessity of minimizing the shadows from foliage. In determining the height, care should be used to suspend the unit so that the rays of light will not shine directly in the eyes of persons approaching, but not so high that the foilage will intercept the rays.

Although the effect of gas illumination with Welsbach mantles is, under ideal conditions, similar to the incandescent unit of small illuminating intensity, the esthetic effect is less impressive. The wide variation in candle-power during the life of the mantle is also objectionable, while the cost of operation is in favor of the series incandescent system. For these and other reasons of less importance, the use of gas for street illuminating purposes is being rapidly replaced by the more modern system of series incandescent lighting.

Constant Current Transformer for Incandescent Lamp Circuits

The following table, compiled from results obtained from actual tests, serve to show the wide variation of candle-power during the life of a Welsbach mantle:

City	Maximum Candle-Power	Minimum Candle-Power	Average Candle-Power
(1)	55.0	21.5	36.7
(2)	25.0	6.5	16.8
(3)	55.1	16.3	27.8

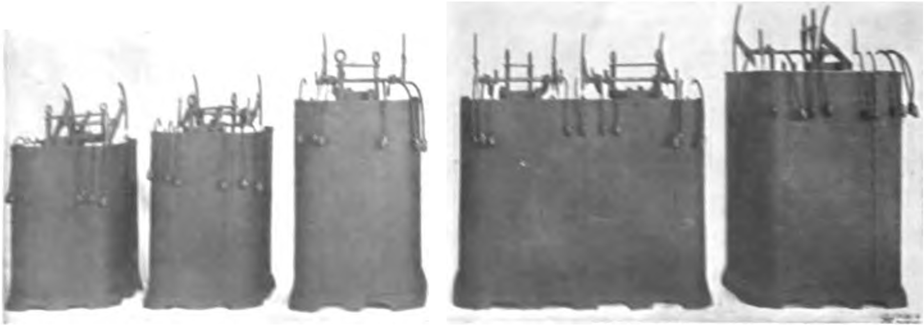
In making a suitable comparison of the operating costs of the Welsbach mantle and tungsten lamp, it will be necessary to take the 60 c.p. tungsten lamp, as the Welsbach mantles are rated at 60 c.p. Basing the comparison on 4000 hours yearly burning, and allowing three renewals per year for tungsten lamp, the following results are secured:

One 60 c.p. tungsten lamp consumes 75 watts, and when operating 4000 hours per year, requires 300 kw. hours.	
300 kw. hours, at 1½ cents per kw-hr. . .	$4.50
Three renewals at $1.215 each . . .	3.65
Total cost per lamp per year . . .	$8.15
One 60 c.p. Welsbach mantle consumes 3½ cubic ft. of gas per hour and when operating 4000 hours per year, requires 14000 cu. ft.	
14000 cu. ft. at $.75 per 1000 cu. ft. .	$10.50
Maintenance at 3 cents per night (365 nights)	10.95
Total cost per year	$21.45
Net saving in favor of the tungsten lamp	13.30

At 50 cents per 1000 ft. for gas, a saving of $9.80 is shown in favor of the tungsten lamp.

Special emphasis should be laid on the fact that the candle-power of the tungsten lamp is practically the same throughout its life, while the gas mantle loses about 25 per cent. of its initial candle-power in the first 100 hours, and at the end of 1000 hours is furnishing only 25 or 30 per cent. of its rated candle-power.

It is evident from what has been said that electric light is the most economical form of street illumination; that the luminous arc is the best lighting unit for general city street lighting; and that the series tungsten incandescent is most satisfactory for suburban lighting and lighting in other localities where conditions demand a unit of minor intensity.



Line of Constant Current Transformers for Arc Lamp Circuits

THERMODYNAMICS*

PART I

BY DR. CHAS. P. STEINMETZ

The electrical engineer entering the field of thermodynamics is at once surprised by the empirical way in which problems are attacked. He is accustomed to general laws in his branch of work, from which results of a general nature can be calculated without the use of tables, receipts, etc.; whereas in thermodynamics he finds a great number of empirical tables. The steam engineer does not calculate as frequently as does the electrical engineer, but depends more on a system of tables and receipts from which he takes his values.

In electrical and mechanical engineering we deal with two different forms of energy; one being electrical energy, the other heat energy. Unfortunately, the terms of heat energy are not as convenient as those of electrical energy, in considering which latter, we can easily make a mental picture and see the physical meaning. In thermodynamics it is practically impossible to form such physical picture, and to gain that clear physical conception which is essential in order to fully understand the subject; the ability to handle these terms in mathematical equations does not imply physical understanding.

Before taking up the laws of heat energy, let us for a moment consider the nature of matter. We picture matter to ourselves as composed of a very large number of very small particles called molecules. Each molecule consists usually of two or more separate particles, called atoms; though sometimes it consists of a single atom. The atom again may be composed of still smaller particles, or electrons. We need not go further, however, than the molecule and atom. The forces of nature are universal in their application, and do not depend upon the sizes or dimensions of the bodies on which they act. Thus between the mass of the molecules, as between all masses, must act the force of gravitation. Again, like everything in nature, the molecules of a body are in motion; this motion may be either regular or irregular. Regular motions are: parallel motions of all molecules, at equal velocity in the same direction; rotary motion of all the molecules around parallel axes, at constant velocity, etc.

The motion of a mass is energy; the motion of the molecules of a body thus represents energy, and the different forms of molecular motion, different forms of energy. The transformation of energy from one form to another thus appears as a transformation of one form of motion into another. The mode of motion that represents a particular form of energy is unknown, except in a few instances; but when dealing with heat energy we find a number of characteristics that are very different from those of any other form—characteristics that are essentially identical with those which should be expected from the energy of irregular molecular motion. Thus the hypothesis that heat energy is the energy of irregular molecular motion is founded on a very reasonable basis.

We find, for instance, considering the general laws of mechanics, that the transformation of any form of regular motion into irregular motion, must necessarily be very complete—must, in fact, be perfect; since it is merely the destruction of regularity; Similarly the conversion of any form of energy into heat is practically perfect.

On the other hand, the conversion of irregular motion into regular motion is very incomplete and is, therefore, inefficient. Correspondingly, all conversions of heat energy into other forms of energy are very inefficient.

If we transform one form of regular motion into another form of regular motion, one form of energy into another form of energy, some of the motions of the molecules lose their regularity—become irregular motions. Thus in any transformation of energy, some of the energy is lost by conversion into heat.

Molecular Motion

Molecular motion may be either progressive or rotary motion, or a combination of both. Molecules may progress onward or they may rotate around an axis, and in either case the motion may be continuous or may be oscillating; that is, the molecule may progress onward continuously, or may move a distance, stop and return again, oscillating around the position of equilibrium. The rotation may be continuous around its own axis and in the same direction, sometimes increasing or decreasing in rapidity, or it may revolve, stop and rotate back again. We thus have four possibilities: progressive motion, and rotary motion, and in both cases either continuous or oscillating motion.

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*Lecture delivered before Schenectady Section A.I.E.E.

Suppose a molecule to move in a given direction, and the resultant force of gravitation of surrounding molecules to be acting in this direction, the molecule will then accelerate in velocity in the direction in which the force acts. Then again, the resultant force may be in opposite direction, when the molecule will decrease in velocity and slow down, due to the opposing force. It may sometimes be in a region in which the force exerted is in the direction of its motion, accelerating it, and at another time the force may be in the opposite direction, retarding it. If the velocity is fairly low, that is, if the heat energy of the body is small (the temperature low), the velocity of the motion will be decreased in the region of retarding forces, and the molecule will be stopped and will trace back over more or less the same path, and will thus oscillate around the position of equilibrium. Thus, the average position of each molecule is fixed in its relation to that of adjacent molecules. In other words, the molecules have fixed relative positions, or the body has a constant shape and volume and is a solid.

Where the velocity of the molecule is sufficient to carry it across the region of opposing forces so that it enters the region of assisting force, that molecule will not return, but will move onward continuously.

If molecular orbits thus cease to be oscillating around a fixed center, and change to continuous, progressive motion, the molecules no longer have fixed positions in relation to each other; the body then ceases to have a definite shape and becomes a fluid.

At velocities, then, where the molecular orbit is progressive, the body is a fluid. Where the motion is oscillatory, the body is a solid.

The laws of the motion of bodies have been more or less completely investigated. Astronomy is really the science of the laws of motion of bodies under the laws of gravitation, and we can apply those laws here; since they do not depend upon the size of the bodies—whether great or small, nor whether they are close together or separated by millions of millions of miles.

Consider, as the simplest case, two bodies acting upon each other, one body of mass m, and velocity s attracted by a body m_1 at distance r. The molecules will first approach each other and then recede. At one position you have velocity s and distance r, and at the other, the velocity s_1 at distance r_1. In the first position the force acting between the molecules is, by the law of gravitation,

$$f = \frac{a\,m\,m_1}{r^2} \tag{1}$$

where a is gravitation constant.

The kinetic energy which the molecule has in the first position is $\frac{m\,s^2}{2}$. The energy of the second position is $\frac{m\,s_1^2}{2}$. The force acting does work, increasing the energy of the molecules as the molecules approach each other.

The work done by the attractive force as m approaches m_1 by a distance dr is

$$f dr = \frac{a\,m\,m_1}{r^2}\,dr \tag{2}$$

During the change of distance from r to r_1 the work done is:

$$\int_r^{r_1} \frac{a\,m\,m_1}{r^2}\,dr$$

Therefore the energy in the new position, which is the difference between the original energy and that corresponding to the work of gravitation, is:

$$\tfrac{1}{2}\,m\,s_1^2 = \tfrac{1}{2}\,m\,s^2 + \int_r^{r_1} \frac{a\,m\,m_1}{r^2}\,dr \tag{3}$$

or

$$s_1^2 = s^2 + 2\,a\,m_1 \left(\frac{1}{r_1} - \frac{1}{r}\right) \tag{4}$$

If therefore

$$r_1 < r \tag{5}$$
$$s_1 > s$$

that is, the velocity of body m increases when approaching, decreases when receding from, body m_1.

If $r_1 = r,\ s_1 = s$ (6)

that is, at the same distance from m_1 body m has again the same velocity. Or, in other words, when two bodies, as two molecules, approach each other, move around each other, and then recede again, they recede with the same velocity with which they approached each other. That is, the interaction of two bodies by the law of gravitation does not result in the transfer of energy from one body to another.

We can apply this equation in determining whether the molecules will separate to infinity. In this case $r_1 = \infty$.

The velocity left to the body m when separating from the other body to infinite distance is:

$$s_1^2 = s^2 - 2\frac{a\,m_1}{r}$$

or
$$s_1 = \sqrt{s^2 - \frac{2\,a\,m_1}{r}} \qquad (7)$$

or if both bodies have the same mass, m, as two molecules of the same gas, $m_1 = m$, then

$$s_1 = \sqrt{s^2 - \frac{2\,a\,m}{r}} \qquad (8)$$

If, therefore, $s^2 < \frac{2\,a\,m}{r}$ s_1 is imaginary, that is, the masses m can separate only a finite distance from each other, and must circle around each other in closed orbits, sometimes going a little further away and sometimes coming nearer. The difference in distance may be very great, but the molecule cannot escape from the other to an infinite distance.

If $s^2 > \frac{2\,a\,m}{r}$, $s_1 > 0$, that is, the masses m move away from each other into infinite distance.

This means that when s = mean molecular velocity, r = mean molecular distance, m = mass of the molecule, and a = gravitation constant; if

$$s^2 < \frac{2\,a\,m}{r} \qquad (9)$$

the molecules of the fluid cannot move away from each other beyond a finite distance, but circulate around each other in closed orbits, that is, have a constant mean distance from each other, and the body is a fluid of constant volume, that is, a liquid.

If
$$s^2 > \frac{2\,a\,m}{r} \qquad (10)$$

the molecules of the fluid move away from each other to infinity, and the fluid is a gas.

The molecular velocity:

$$s_0^2 = \frac{2\,a\,m}{r} \qquad (11)$$

is thus the velocity at which the fluid loses its volume, or the liquid turns into a gas, and is the characteristic of the boiling point of the substance.

Three states of matter can be distinguished:

(1) s so low that the progressive motion is not continuous, but oscillating; constant shape and constant volume; solid.

(2) s sufficiently high to give continuous progressive motion, but $s^2 < \frac{2\,a\,m}{r}$; constant volume, but no constant shape; liquid.

(3) $s^2 > \frac{2\,a\,m}{r}$; neither shape nor volume constant, but the body fills all available space; gas.

With increasing heat energy, the body passes two critical points—the melting point and the boiling point.

If two different gases—one with heavy molecules and the other light—come together there will be an interchange of energy and all the molecules will reach the same average energy. Thus if a gas of molecular mass m_1, and mean velocity * s_1 is mixed with a gas of molecular mass m_2 and mean velocity s_2, we have:

$$\frac{m_1\,s_1^2}{2} = \frac{m_2\,s_2^2}{2} \qquad (12)$$

From equation (12) we have the following:

$$s_1 \div s_2 = \frac{1}{\sqrt{m_1}} \div \frac{1}{\sqrt{m_2}} \qquad (13)$$

That is, the molecular velocities of all gases which are mixed with each other are inversely proportional to the square root of their molecular masses, that is, molecular weights.

All actions of gases which depend upon their molecular velocities, as diffusion through a porous diaphragm, are therefore inversely proportional to the square root of their molecular weight. The above law therefore permits the calculation of molecular velocities from molecular weights as soon as the molecular velocity of one body is given.

From the definition of the term "temperature," bodies have the same temperature, if, when in contact with each other, no flow of heat energy occurs between them, that is, no interchange of heat. Thus gases which are mixed with each other have the same temperature. That is, all gases which have the same temperatures have the same $\frac{m\,s^2}{2}$ of their molecules.

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* The so-called mean or average molecular velocity, is not the arithmetic mean of all molecular velocities, but is the velocity corresponding to the arithmetical mean of all molecular energies, $\frac{m\,s^2}{2}$; that is, it is the *effective mean*, or the square root of mean square of all molecular velocities. The term is to be so understood when used in this article.

Thus the $\frac{m\,s^2}{2}$ of all gases is proportional to, and can be assumed as a measure of the temperature; it is so used as a measure of the so-called absolute "temperature."

$$T = q\,\frac{m\,s^2}{2} \tag{14}$$

The impact, or moment of a mass m at velocity s is $m\,s$. If n = number of molecules per unit volume of a gas, s the molecular velocity, the number of impacts of the molecules on unit area of boundary surface is $n\,s$.†

Since the impact force per molecule is $n\,s$, the total impact force, or pressure, exerted by the gas on unit area is

$$m\,s\,.\,n\,s = n\,m\,s^2.$$

With two gases which have equal pressures:

$$p_1 = n_1\,m_1\,s_1^2 \text{ and } p_2 = n_2\,m_2\,s_2^2 \tag{15}$$

hence,

$$n_1\,m_1\,s_1^2 = n_2\,m_2\,s_2^2. \tag{16}$$

At equal temperature (equal molecular energy) we have from equation (12):

$$\frac{m_1\,s_1^2}{2} = \frac{m_2\,s_2^2}{2} \tag{17}$$

thus give by dividing:

$$n_1 = n_2 \tag{18}$$

From this, it results that any two gases, at equal pressure and equal temperature, have the same number of molecules per unit volume, n; and the weight per unit volume of all gases at equal temperature and pressure —that is, the specific weight of the gas—is proportional to its molecular weight. The molecular weight of a gas is thus determined by measuring its specific weight.

Since the pressure of a gas is

$$p = n\,m\,s^2$$

and the absolute temperature

$$T = q\,\frac{m\,s^2}{2}$$

we have:

$$p = \frac{2}{q}\,n\,T \tag{19}$$

That is, the pressure of the gas is proportional to its absolute temperature at constant number of molecules per unit volume, or constant volume of the gas.

The volume of constant mass of gas is inversely proportional to the number of molecules per unit volume, n.

$$V = \frac{S}{2\,n} \tag{20}$$

hence substituting in (19) we have:

$$p = \frac{R\,T}{V} \text{ or}$$

$$p\,V = R\,T \tag{21}$$

where R is a constant of the gas.

In two gases,

$$p_1\,V_1 = R_1\,T_1 \tag{22}$$

and

$$p_2\,V_2 = R_2\,T_2 \tag{23}$$

for the same pressure,

$$p_1 = p_2$$

and at the same temperature,

$$T_1 = T_2$$

By dividing (22) by (23) we have:

$$\frac{V_1}{V_2} = \frac{R_1}{R_2} \tag{24}$$

The specific weight of different gases at constant pressure and temperature, that is, the weight per unit volume, is proportional to the molecular weight, since the number of molecules per unit volume is the same for all gases; and the volume per unit weight is therefore inversely proportional to the molecular weights.

If M_1 and M_2 are the respective molecular weights of two gases, V_1 and V_2, the volumes per unit weight at constant pressure and temperature then:

$$\frac{V_1}{V_2} = \frac{M_2}{M_1} \tag{25}$$

hence, substituting in (24) we have:

$$\frac{R_1}{R_2} = \frac{M_2}{M_1} \tag{26}$$

or,

$$R_1 = \frac{r}{M_1}$$

$$R_2 = \frac{r}{M_2}$$

and,

$$p\,V = \frac{r\,T}{M} \tag{27}$$

This is the fundamental equation of all theoretical gases, where p = pressure per unit surface, V = volume per unit weight, T = absolute temperature, M = molecular weight, and r = a constant, which is the same for all gases, and is

$$r = 848,$$

if p is given in kilogrammes per square meter, V in cubic meters per kilogrammes, and T in centigrade.

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† While it is convenient, and for the present purpose permissible, to speak of the "impact" of molecules on the boundary surface, the actual motion is obviously an orbital one, and no more an impact than the motion of molecules around each other is an impact or a collision, as is frequently stated for simplicity of expression.

That is, in all gases, for a given quantity, *i.e.* weight of gas, we have:

The pressure, at constant volume, is proportional to the temperature.

The volume, at constant pressure, is proportional to the temperature.

The pressure, at constant temperature, is inversely proportional to the volume.

The volume, at constant temperature, is inversely proportional to the pressure.

At constant temperature, the pressure at constant volume, or the volume at constant pressure, are inversely proportional to the molecular weight.

Temperatures can therefore be measured by the change of pressure at constant volume, or by the change of volume at constant pressure.

The absolute temperature, T, as measured by equation (27), becomes zero at $-273°$ C., that is, the absolute temperature T counts from $-273°$ C. as zero point.

At $T=0$, or $-273°$ C., p and V would therefore be zero, and $\frac{m s^2}{2}=0$.

In the preceding, the volume or space occupied by the mass m of the molecule has been neglected as small compared with the space between the molecules, and the equations derived above, therefore, are approximate only, and have to be modified by correction for the actual space occupied by the molecules. Thus, for $T=0$,the volume V would not become zero, but only equal to the space occupied by the masses m of the molecules, if before this temperature were reached the character of motion had not already changed from that of a gas to a liquid and solid. For most practical cases, the correction for the mass of the molecules is so small that it can be neglected, except at very high pressure, and even then is not considerable.

(To be Continued)

CENTRIFUGAL PUMP FIRE-BOATS*

By Charles C. West

The modern fire-boat has become a necessary adjunct to the fire departments of sea, lake or river cities, and is viewed by underwriters as an important factor in determining insurance rates.

Not only is the fire-boat a necessity for the extinguishing of fires along a water front, or protecting shipping, but it is now rapidly coming into use as an auxiliary water supply to the municipal pumping plants in cases of large or dangerous conflagrations. The pressure maintained and the volume supplied by the ordinary water supply system of the average city is insufficient in extreme cases, and most of the large cities are now installing the system of water mains drawing their supply directly from the water front.

The city of New York has lately opened some high-pressure pumping stations on different points in the water front for fire protection, consisting of multiple stage centrifugal pumps operated by electric motors. A good fire-boat with its shore connections accomplishes, of course, the same purpose. The commercial advantage almost always causes a business congestion near a water front; this demands ample protection, and therefore the size and capacity of fire-boats have grown with the cities.

Owing to the comparatively temporary nature of American building construction, the fire-boat has been developed in the United States more rapidly than in foreign countries, and to-day the boats of largest capacity are to be found over here.

In the design of a fire-boat local conditions are of course of importance in determining such considerations as speed, ice-breaking and maneuvering qualities, etc.; but in view of the fact that a fire-boat is merely a self-propelled pumping plant, interest centers in the pumps and the many fittings not common to other craft. For years there has been little difference in the great number of fire-boats built in all parts of the country. In most cases identical pumping machinery was used, differing only in the number of units installed. These units consisted of double-cylinder, vertical, inverted reciprocating pumps, each unit having a rated capacity of about 3,000 gallons per minute.

In order to get a smooth nozzle stream and sufficient pressure and have the pumps contained in the limited space offered by an ordinary hull, it was necessary to run these pumps at an exceedingly high speed. As a consequence, however, the strains on the machine were enormous, in addition to which was the ever-present danger of valve trouble. The reciprocating pump, however, has served its purpose creditably, but the demand which has come for higher pressures makes its future adoption questionable.

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*From paper read at the sixteenth general meeting of the Society of Naval Architects and Marine Engineers, held in New York, November 19 and 20, 1908. Published by permission.

The development of the centrifugal pump of the multiple stage variety is comparatively recent, and the advent of the steam turbine has aided in its adoption owing to the high speed obtainable. In the boats equipped with turbines and two-stage centrifugal pumps in use at the present time, there has been no difficulty in obtaining higher pressures than are possible in the reciprocating pump. This pressure can easily be increased by increasing the number of stages, with no effect on the structure or working of the pump.

Fig. 2 shows a design of centrifugal pump boat, designed by Mr. W. I. Babcock for the city of Chicago.

The turbines used so far in operating these centrifugal pumps have been of the horizontal impulse type. While this type of turbine possesses the advantage of being more compact than the reaction turbine, it is also claimed by turbine builders that it can be started without being warmed up, a performance said to be dangerous in the reaction turbine owing to the liability of warping the spindle.

In the operation of fire-boats of late years the latest practice has been to use hose lines less, and to discharge the streams either directly from the boat from stationary nozzles, or, as before mentioned, into underground water mains. With the powerful streams now at the command of the firemen, it is of course necessary that the huge nozzles used be not only fixed to the boat, but also mechanically operated. This is done by affixing them either to towers, tops of deck-houses, or platforms, as shown in the various drawings. Hose connections are made either with the bulb turrets or quick-opening valves on the sides of the deck-houses.

Inasmuch as the interest in a fire-boat centers in her pumps, and as the turbine centri-

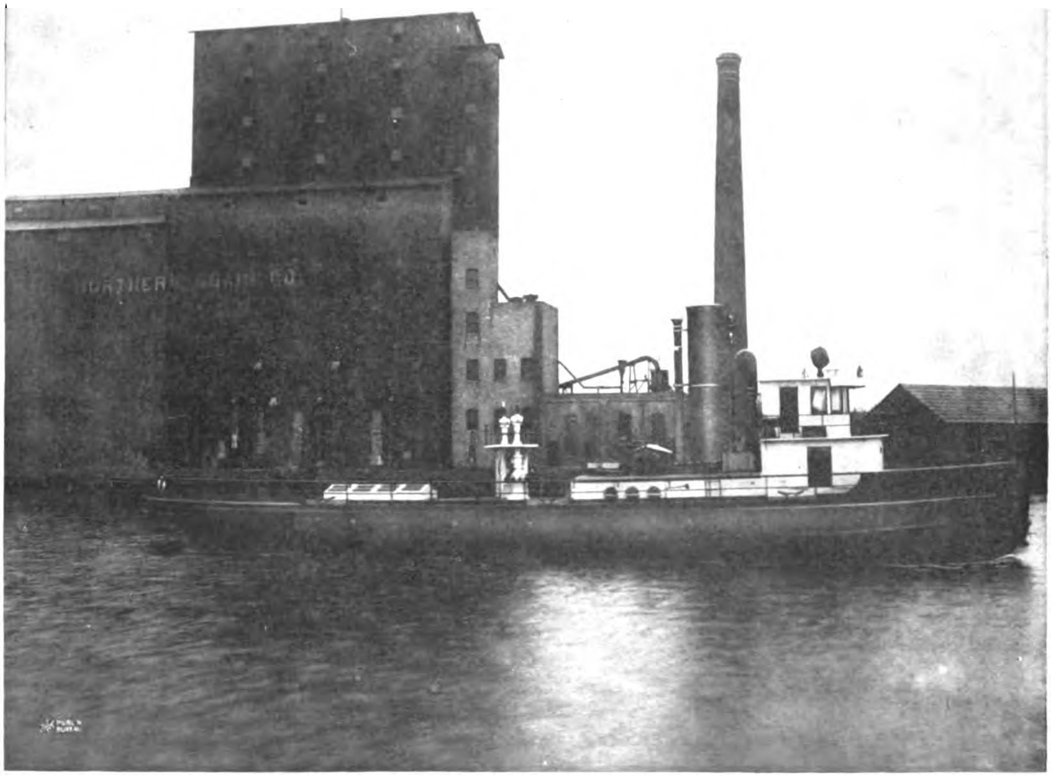

Fig. 1. Fire-Boat for City ot Chicago

fugal pump and outfit represent the latest practice in this line, the writer gives the result of a test made on the first of the two 9,000 gallon boats designed by Mr. W. I. Babcock for the city of Chicago and just delivered to them.

Inasmuch as these were the first centrifugal pump boats to be used on the great lakes, the results of their tests were watched with much interest.

The general dimensions of these boats, the Joseph Medill and the Græme Stewart, are:—

Length over all, 120 feet.
Length of keel, 109 feet 6 inches.
Beam, 28 feet 0 inches.
Depth, 15 feet 0 inches.
Displacement, 500 tons.
Draught, 9 feet 6 inches mean.

In the plan as illustrated in Fig. 2 it will be noted that a unique propulsive scheme was used. The main pumping and power machinery consisted of two 660 horse-power Curtis turbines direct connected to 200 kw. direct current generators and two-stage centrifugal pumps. The generators served to provide current for the propelling motors which are of the variable speed reversing type. In going to a fire the pump impellers run dry. Control of these motors is possible from both the pilot-house and engine-room, and in the test the captain easily handled his boat without the aid of the engineer.

There are two pumping-generating sets in each boat, and the boats are furnished with twin screws. Steam was supplied by two two-furnace Scotch boilers, 11 feet 6 inches long by 12 feet 6 inches diameter; 1,910 square feet heating surface in each boiler and 42 square feet of grate surface. Forced draft is provided on the closed stoke-hole system.

In the Chicago river, where these boats are to be used, most of the old center pier bridges have been removed and it is necessary at times for a fire-boat to maintain itself in the middle of the river. On this account mooring spuds were adopted, operated by steam, raising and lowering gear.

As shown in Fig. 1 the principal water outlets consist of two monitor nozzles placed on a platform directly above turrets on which are the hose connections. The pumps, though usually run singly, can be compounded, and a nozzle pressure of over 300 pounds was thus obtained on the test, with a resultant capacity of about 5,000 gallons per minute.

In connection with this boat, the results of an eight-hour endurance test may be of

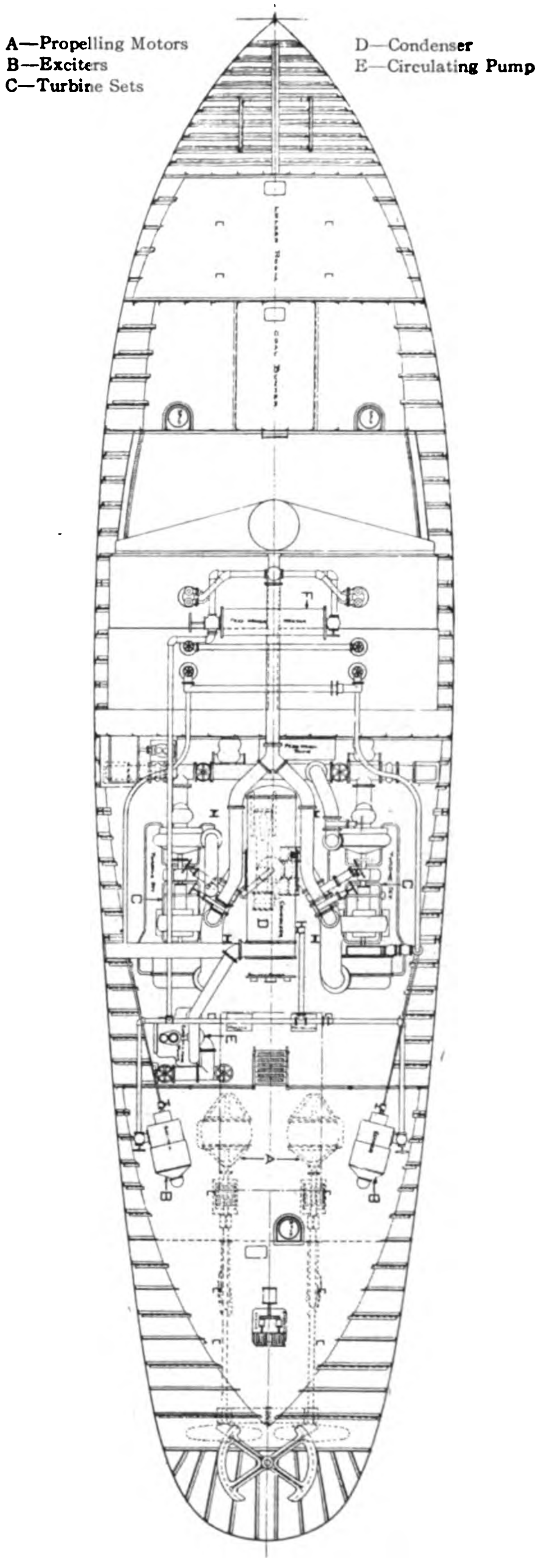

Fig. 2. Plan of Fire-Boat

interest. Owing to the late date at which the test was held, it is impossible to work up the test in more detail, but the data given show the average performance of the machinery during this run.

Coal consumption was measured by leveling bunkers before and after test, and estimating the weight from the cubical contents, the weight per cubic foot being determined from samples.

Feed water was run through a hot water meter and measured, and the meter afterwards calibrated. The make-up feed which measured the steam consumption of the auxiliaries was also metered, and this reading, deducted from the total water used, gave the steam consumption of the main turbines.

Pressures at the nozzle were measured by a Pitot tube held in the stream, and the discharge computed from the equation—

$$Q = 29.9\,D^2\sqrt{P}.$$

Where

Q = Discharge in U. S. gallons per minute.
D = Diameter of nozzle in inches.
P = Pressure reading of Pitot tube in lbs.

The summary of the test follows:—

Date	Oct. 28, 1908.	
Duration of run	8 hours	
Barometer	29.53 in.	
TEMPERATURES		
External air	50°	
Engine-room	54.8°	
Circulating water, final	75°	
Circulating water, initial	51°	
Circulating water, range	24°	
Dry vacuum pump discharge	131.3°	
CENTRIFUGAL PUMP FIRE-BOATS		
Feed water, final	164.0°	
Feed water, initial	106.4°	
Range	57.6°	
REVOLUTIONS		
Turbine, starboard	1,660	
Turbine, port	1,634	
Circulating pump	285	
Dry vacuum pump	123	
Blower engine	537	
Strokes per minute (single strokes):—		
Hot-well pump	133.6	
Feed pump	95.2	
PRESSURES		
Boiler pressure,* starboard	156.8 lbs.	
Boiler pressure, port	156.5 lbs.	
Main steam at turbines, starboard	156.5 lbs.	
Main steam at turbines, port	154.0 lbs.	
Condenser vacuum gauge	27.3″	
Draft gauge in fire room	.83″	
Centrifugal fire pumps, starboard	157.5	157.25 lbs. mean
Pressures, port	157.0	
Nozzle pressure, starboard	101.3	101.15 lbs. mean
Nozzle pressure, port	101.0	
Number of nozzles	2	
Diameter of nozzles	4″	
Gallons water discharged per nozzle per minute	4,800	
Gallons, total boiler discharge per minute	9,600	
Gallons, total boiler discharge per hour	576,000	
Water horse-power of pumps, each	442.5	
Water horse-power of pumps, total	885.0	
Coal burned, total	26,500 lbs.	
Coal burned, per hour	3,310 lbs.	
Coal burned, per square foot G. S. per hour	39.4 lbs.	
Feed water, per hour	23,750 lbs.	
Make-up water, per hour	2,206	
Steam consumption:—		
Steam turbines	21,544 lbs.	

Because of the unusual character of propelling machinery, some items in connection with the trial trip performance may be of interest. The boat was run over a course from the Manitowoc breakwater to a point opposite the breakwater at Two Rivers, Wisconsin. The two breakwaters are very nearly parallel and the course as measured from the Government charts is five and one-half miles. The time of start and finish was taken, and readings of r.p.m. and switchboard were taken at five-minute intervals. The results follow:

Date	Oct. 30, 1908.
Distance	5½ miles.
Time mean of two hours	28.25 min.
Speed (statute miles per hour)	11.7
R.P.M., starboard motor	179
R.P.M., port motor	178
Developed horse-power:—	
Motors, starboard	166
Motors, port	203
Output of generators, starboard	181
Output of generators, port	223
Motor efficiency, starboard	91.0%
Motor efficiency, port	91.8%

The data obtained from the foregoing test show not only that the centrifugal pump is a more powerful and reliable machine than the old type, but also that the greater economy of the turbine outfit makes it possible to do more work with about half the boiler capacity. Comparing the water rate of these turbines with that of a high-pressure pump taking steam for almost full strokes demonstrated the fact that there is probably no boat afloat of the same size that has the pumping capacity of the Joseph Medill.

While the guaranteed capacity of the boat was 9,000 gallons per minute, the eight-hour endurance test showed an average delivery of 9,600 gallons. As may be surmised, the builders ran the test with the idea of fulfilling their contract and not to make a record. It is safe to say that this boat, if crowded, will deliver between 10,000 and 11,000 gallons of water per minute at 150 pounds pressure.

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* Boiler gauges are placed in engine-room over switchboard. This would probably account for the small drop in pressure between boiler and turbines.

FOREIGN TRANSPORTATION PROBLEMS

By E. F. Colyer

The shipping interests of the General Electric Company are world-wide. The distinctive monogram branded on its packing cases may be seen in all quarters of the globe, from the Yukon to the Transvaal, from Honduras to Tasmania. With the volume of the Company's export trade and the diversity of the conditions to be met at destination, it is but natural that all sorts of forwarding problems should be presented in the regular routine of shipping its products abroad.

It is obvious that the varying customs requirements of some two score countries must call for widely different methods in the handling of shipments, but it is not the purpose of this article to discuss the complexities of shipping documents, but rather to describe some of the physical conditions which have to be provided for, the neglect of which may result in difficulties apparently quite disproportionate to the actual cause.

One of the first points to be considered in preparing material for export shipment is the method of transport from port of entry to final destination; whether there is rail communication, inland water service, or whether more primitive means must be relied on. The apparatus for the power transmission scheme in the State of Kashmir, India, had to be transported in bullock carts, 150 miles over mountain roads, and a limit of four tons was fixed, beyond which weight no piece might go. Five hundred pounds was considered the most desirable weight for this method of transport. It is interesting to note that twenty to thirty days were consumed by the bullock trains in making the 150 mile trip.

With a limit of four tons, a certain amount of sectionalizing of apparatus was necessary, but the extreme limit of subdivision is required when recourse must be had to muleback transport. In such cases shipment in 150 to 175 lb. packages must be arranged. If burros only are available, the packages must only weigh about 125 pounds each. While a mule may carry 350 pounds and a burro 250 pounds, it is somewhat difficult to pack a single case of this weight, whereas two cases may be readily slung, one on either side.

Muleback transport is still the only reliance of many substantial villages and towns in Central and South America. Others, however, count on a form of water transport which can hardly be considered much of an improvement. A recent shipment for Nicaragua was prepared with the expectation that during a part of its voyage it was liable to be repeatedly submerged. This portion of its journey to the interior will be made in canoes, which will have to be lightened at frequent intervals to enable them to pass shallow places, the cargo being deposited on the nearest available rock. If the rock happens to be a round one the chances against the cases remaining above water are poor. For such conditions, the use of small metal lined cases are imperative.

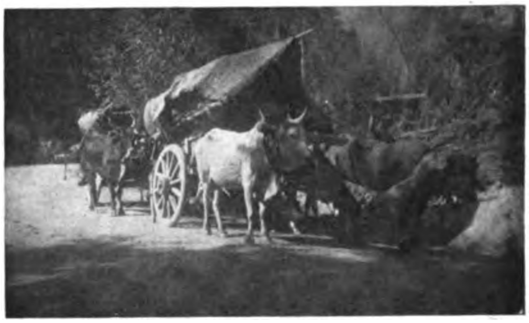


Fig. 1. Transmission Line Material for Kashmir Plant in Transit Team of Bullocks and Water Buffalo

Even where rail transport from the coast is available, the limit to the size and weight of packages is invariably very much less than can be taken care of in shipment from the factory to New York. The clearances on foreign railways are less than in the United States, and the rolling stock is of considerably reduced capacity. Within a couple of years, advices from Japan were to the effect that the standard freight car would carry but five tons, and there were but one thirty-ton and six fifteen-ton cars in the country, these being obtainable on due notice to the Government. It is on record that a generator of very moderate dimensions was shipped to that country, no intimation having been given the manufacturers that because of rail clearances a split frame machine would be desirable. On arrival, it being discovered that if standard equipment were used the machine could not be got through the tunnels, the customer was politely informed that it would be necessary that a special car be provided, unless he was prepared to wait until the tunnels were enlarged, a matter of a year or two.

In the shipment of large turbo-generator sets, the inability of foreign roads to handle packages in the same way that American roads do, is most marked, and special provisions for transport on available cars must be made before shipment from the factory. As an example, two 3000 kw. sets for the Tuilieres (France) installation, may be mentioned. Several pieces in this shipment were larger than could be transported from Schenectady to New York, unless dropped below the floor of the cars. The exhaust base, for instance, which was 13 ft. 6 in. in diameter, had to be loaded on the car with its lowest point one foot below the level of the car floor, the available clearance above floor of car being about 12 ft. 6 in. On the line from Bordeaux to Tuilieres, however, the total clearance above rail made it necessary that the piece be carried within four inches of the rail, there being then but three-quarters of an inch clearance at the top. These pieces weighed 50,000 pounds. A framework had to be provided to permit of their being carried on cars from factory to New York. At New York, additional timbers were attached to allow pieces to be carried upright in steamer's hold, and on arrival at Bordeaux the greater part of this skidding had to be removed, the pieces than being supported by cross timbers which rested on the side frame of the car. As these cross timbers were about 8 ft. 6 in. long, they were not placed in position on the framework when leaving the works, shorter pieces being substituted during transit to Bordeau. The longer timbers would have increased the dimensions of the package for ocean carriage by an excessive amount. The bucket wheels, diaphragms and wheel casing were similarly boxed. (See Fig. 2). A modification of this method of packing was employed in shipping a couple of 3500 kw. turbines to Rome.

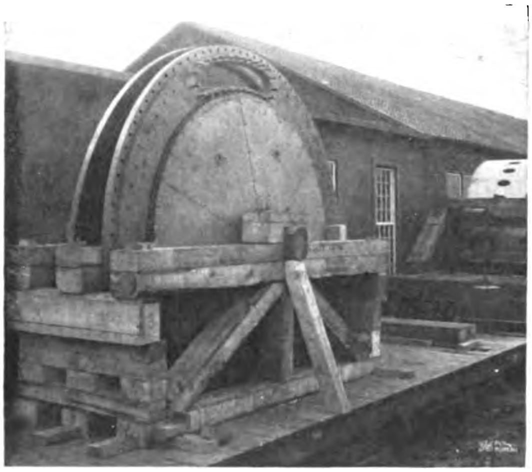


Fig. 2. Wheel Casings of 3000 Kw. Turbines for Tuilieres, France

In the shipment of a 9000 kw. turbo-generator for Vitry (France), the conditions were somewhat reversed from what has been customary. The apparatus for this station was transported by barges from Havre, up the Seine to the power house near Paris, so that the limiting feature was the transportation facilities from Schenectady to New York. The stationary armature of this set weighs 118,000 pounds net, and measures 10 ft. 11 in. in diameter and 8 ft. 7 in. in height. The standard flat car is about nine feet wide, so that the bare armature projected almost a foot beyond each side of the car. Boxing at the factory was out of the question, and the necessary framework was therefore made up and shipped separately, to be put on upon arrival at New York.

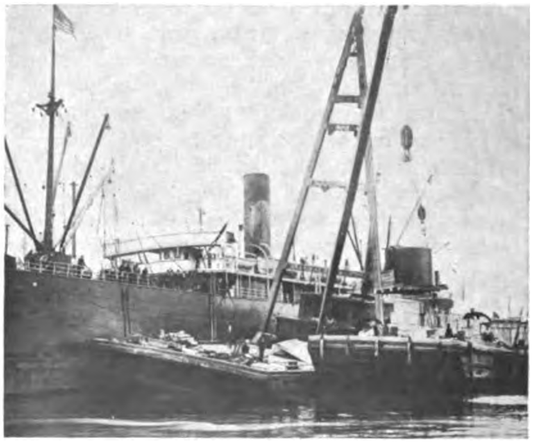


Fig. 3. Lifting Sixty-Ton Armature from Lighter into Steamer

For the handling of such pieces as this, the harbor of New York is very well equipped. In foreign ports the cranage facilities are usually limited to fixed shears, or to cranes forming part of the dock equipment. New York, however, is served by a very complete system of floating derricks, those operated by the railroads having a capacity up to 20 tons. Besides these, there are a large number operated by independent concerns, having capacities up to 50 or 100 tons, while the

Merritt & Chapman Derrick & Wrecking Company have one boat capable of handling pieces up to 250 tons in weight. Freight steamers do not customarily handle pieces in excess of five tons with their own tackle, although sometimes, when lines run to ports where the cranage facilities are limited or excessively expensive, the boats are equipped to handle pieces up to 20 tons in weight. All deliveries of heavy apparatus are made to steamers by lighters, the smaller floating derricks being also used for this purpose, while derricks of larger capacity are customarily used merely for lifting from car to lighter and from lighter to steamer.

During extremely severe weather the movement of lighters in the harbor of New York may be somewhat hampered by the formation of ice, or by wind driving drift ice into the slips between piers. As a rule, however, the weather has very little effect on the movement of freight about the harbor, and from cars to steamer. On the other hand, in some foreign countries they are not so fortunate, and loading and unloading from or into lighters is attended with very considerable difficulty. In a number of South American ports these operations are frequently carried on in what is practically an open roadstead, and it requires a nice degree of judgment to lower cargo without damage to the deck of the receiving lighter, when the lighter is being vigorously tossed up and down by the waves. Not infrequently, large pieces of apparatus are dropped overboard in the process of transfer, and this risk is taken into account in the rates demanded by the insurance companies.

In foreign ports where only fixed shears are available for the handling of heavy lifts, the steamer itself must be moved under the shears, an operation attended with considerable trouble, and sometimes delay. If the customary berth of the vessel be in a dock not so equipped, it is frequently necessary to wait for high tide to permit transfer from one dock to another, the great rise and fall of the tides requiring that the various docks be built on the same principle as canal locks, and only to be entered at flood tide. In the Tuilieres shipment to which reference has been made, the shears were needed for the discharge of the turbines; and as a shipload of locomotives was despatched from Philadelphia to Bordeaux at about the same time that the two turbines left New York, special arrangements were necessary to ensure that the steamer carrying the turbines should arrive first, as heavy demurrage charges would have accrued had it been necessary to await the discharge of the locomotives.

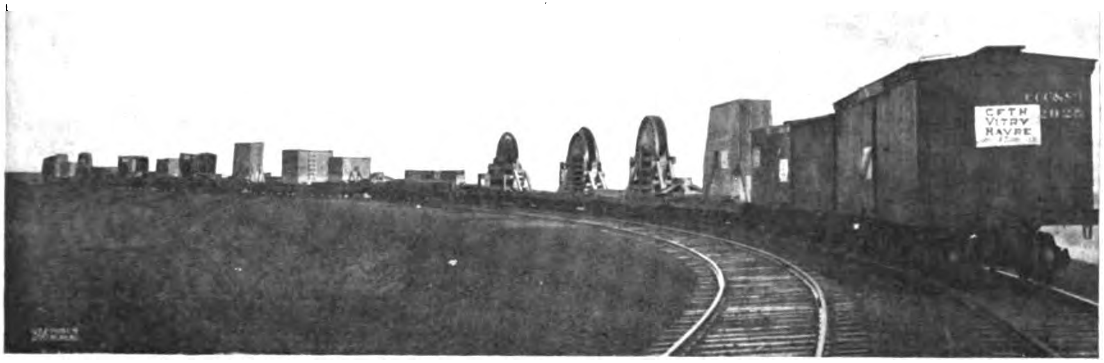


Fig. 4. Train of Seventeen Cars Carrying a 5000 Kw. Turbo Generator for Vitry, France

In stowing cargo, it is essential that heavy freight be placed at the bottom of the hold. The up-to-date carrier is built on very much the same classic lines as a canal boat; it is divided horizontally by one or more decks, and vertically by a number of partitions separating the various holds. The lower hold may be from 14 to 20 feet deep, extending the full width of the ship, and 30 to 60 feet forward and aft. This is stowed solid so that the pitching and rolling of the ship will not cause any movement of the cargo. As a matter of course, apparatus that must be carried in such a manner must needs be very substantially boxed, not only to withstand the strains resulting from its own load, but also those resulting from the other cargo with which it is in intimate contact. There is still another reason: after covering the floor of the hold with large cases of varying sizes and shapes, sundry small openings are usually apparent, and these are generally stopped up with smaller packages. In filling these openings, due care is not always taken to see that cases are gently lowered to the bottom; a case which seems to fit is frequently placed over the opening and dropped, sometimes with unfortunate results to its contents.

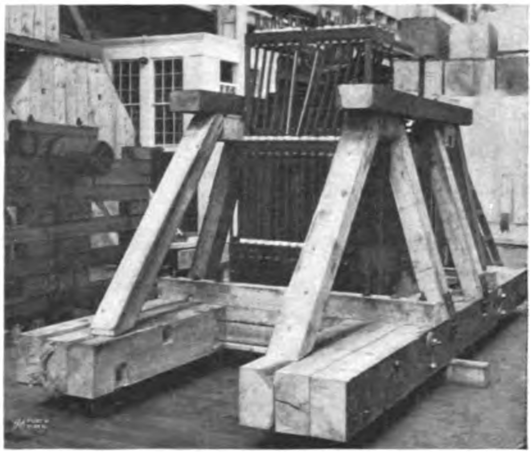


Fig. 5. 2000 Kw. Transformer for Necaxa, Mexico Showing Method of Bracing

The ancient Phoenicians were noted for the ability with which they stowed away the miscellaneous cargo carried by their trading ships. A good deal of this ability is displayed by the better grades of stevedores of the present day, it being remarkable to note the celerity with which cargo is loaded, and the minimum of damage resulting from the manner in which it is handled. A vessel containing 6000 tons of general cargo will arrive, unload, take on a like quantity of outward cargo, and sail within a week. This means the equivalent of 800 carloads, every bit of which must be handled piece by piece, hoisted twenty or thirty feet in slings, and lowered again to the dock or the hold. Yet all stevedores are not so capable nor careful in the handling of cargo. The amount of heavy machinery shipped from the port of New York is yet somewhat limited, and it is not uncommon to find the preparation for the stowing of such machinery altogether inadequate. Pieces weighing up to ten tons are easily slid into position from under the hatch opening if greased planks are used, and small pipe rollers, which may be suitable for pieces of five or six tons, are discarded after a short trial. The efforts of a stevedore unaccustomed to handling heavy machinery, may, however, have a somewhat unsatisfactory outcome until the knack is acquired. In a shipment containing a number of 1000 kw. oil cooled transformers, this fact was made very obvious. Rollers had been used to place one of the transformers in place, the transformer being boxed and lying flat on its side. One end of the case was jacked up about a foot and supported by a couple of pieces of wood to permit of the rollers being withdrawn. It was then proposed to knock out the supports, allowing the transformer to drop flat. It is needless to say that vigorous objection was made to any such procedure, as in spite of the most careful boxing and substantial construction the apparatus would hardly be benefited by treatment of this character.

In the shipment of such apparatus as transformers, due consideration must be given to the manner in which ocean freight rates are figured. The space in a vessel being limited, bulky freight must pay for the room occupied; while on the other hand, cargo of comparatively great weight and small volume is charged for by weight, the maximum displacement of the vessel being likewise a fixed quantity. The practice is to charge at a certain rate per ton of 2240 pounds or 40 cubic feet, ship's option. A further factor is the custom of charging higher rates per ton for heavy pieces, to compensate for the greater risk and difficulty in handling. The increase in rates is progressive with the increase of weights of packages. A transformer in its tank is compact, and pays freight by weight at the rate per ton corresponding to its weight. If disassembled, the core and coils boxed will make a package or packages of dimensions approximately equal to, and frequently greater than the complete transformer, while the tank will represent a corresponding cubic tonnage. The rates per ton will, of course, be less than when apparatus is shipped completely set up, but it is often a question as to whether the reduction in rate is not overbalanced by the increase in tonnage.

In measuring a package to determine the number of cubic feet for which charge is to be made, the extreme overall dimensions are taken, even though these represent nothing more than extended skids, the main boxing being compact. The method of packing the 2000 kw. transformers for the Necaxa (Mexico) plant (Figs. 5 and 6), which was adapted for rail transportation where the question of weight alone governs, would be subject to some modification when water transport only is available. This substantial packing was found fully adequate to permit of several transfers, including the ultimate lowering of the transformers some seven hundred and fifty feet to the bottom of the barranca in which the power station is located; and this, notwithstanding that during transit some of the cases were slung from the small projecting timbers, which were never intended for the purpose.

A popular misapprehension is that for ocean transportation it is necessary to box apparatus in zinc lined cases to protect it against damage from sea water. When it is understood that sea water can come in contact with cargo only as the result of injuries to the vessel so severe as to threaten its very existence, the futility of this precaution becomes apparent. The hold of the usual freight carrier is so free from moisture that when grain is transported it is customary to load it in bulk, and it is obvious that if the incursion of sea water were common, the loss on grain cargoes would be severe. Experience has shown that, instead of being of advantage, metal lined boxes are usually a positive detriment.

While it is necessary to take due precautions against damage to apparatus resulting from condensation, this seems to be best guarded against by providing for as liberal ventilation of the cases as possible. Undoubtedly the best results would be obtained if machinery were crated, so as to permit the freest access of air to all parts; but unfortunately other things have to be considered, and apart from the risk of exposure to the elements after discharge from the steamer, it has been found that small brass parts, oilcloth coverings and the like, have an irresistible fascination for the native in more than one quarter of the globe. Condensation troubles are naturally most in evidence in shipments which are transported long distances, from a cool to a warm climate. The moisture is undoubtedly largely contained in the miscellaneous cargo when stowed in the ship. The comparatively dry cool air becomes heated, absorbs moisture from the merchandise, and in cooling, this moisture is condensed on exposed metal surfaces; these must therefore be protected in some manner. It is almost an impossibility to make or keep a metal lined case absolutely air tight, and it can be readily seen that the smallest pin hole operates as a valve for the admission of moisture laden air, which is then exposed to an excessively large condensing surface of case lining as well as contents.

Reference has been made above to the speed with which vessels are loaded. Not all steamers, however, get away in such short time. For many ports where there is an infrequent and irregular service, it is customary to schedule steamers for certain fixed dates, and if the freight offering is not sufficient to fully load the vessel, to extend the sailing dates from time to time, the boat finally getting away several weeks after original scheduled sailing date. Where there is competition between different lines, it is often difficult to determine which boat will get away first, and the interests of the shippers are thereby injuriously affected; for, in addition to the length of time consumed by freight steamers (which average from eight to nine knots an hour) in passage from port to port, the time lost in port after the receipt of the first part of the cargo must be taken into consideration. The situation of late years has greatly improved, but within a comparatively recent period it was not unusual to receive reports of material having taken four or five months in transit from factory to Australia, New Zealand or Japan. It is nevertheless beginning to be recognized that an adherence to fixed sailing schedules is demanded by present day business conditions and unquestionably irregularity of sailings will sooner or later be confined to ports to which the volume of traffic is small.

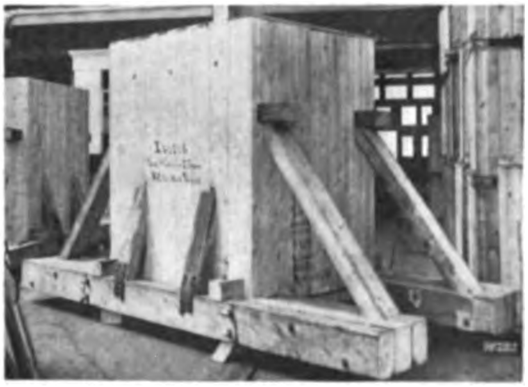


Fig. 6. 2000 Kw. Transformer for Necaxa, Boxed

In conclusion, it may be added that as yet the matter of ocean freights is largely adjusted by competition. Various combinations or agreements are arranged between the different lines, but these have always in prospect that if freight rates are excessive, it is a simple matter for an outsider to step in with tramp steamers and secure a share of the business by offering attractive rates. On any substantial shipment of high grade freight, like machinery, the tramp is ready to figure; and, to prevent the outsider from cutting in, the regular lines must be prepared to meet reasonable competition or lose the business. Charging "all the traffic will bear" is reduced to a science in ocean carrying, with free competition working on behalf of traffic. When employing tramp steamers, it is necessary to make sure that the vessel is of such a character that insurance may be easily and cheaply effected, and that the other cargo is of such a nature and is stowed in such a manner as to prevent injury to the apparatus. If care is not taken in these respects, the consignee is liable to find that the steamship agents have poured grain in and around the machinery, and that the cases on arrival contain as much cargo belonging to others as to the rightful owner.

VARIABLE RATIO CONVERTERS

("Split Pole" Converters)

PART III

BY CHAS. P. STEINMETZ

Considering an n-phase converter of normal ratio, let

E_0 = direct current voltage

I_0 = direct current

E^0 = alternating voltage between adjacent collector rings (ring voltage)

I^0 = alternating current between adjacent collector rings (ring current).

Then, as can easily be seen from the voltage diagram:

$$E^0 = \frac{E_0 \sin \frac{\pi}{n}}{\sqrt{2}} \qquad (1)$$

and since, by the law of the conservation of energy, the output must equal the input, neglecting losses:

$$I^0 = \frac{I_0\sqrt{2}}{n \sin \frac{\pi}{n}} \qquad (2)$$

where I^0 is the energy current, corresponding to the direct current output.

The voltage ratio of a converter can be varied by either of two methods, as discussed in the preceding sections of this article:

(1) By shifting the direction of the magnetic flux.

(2) By the superposition of a third harmonic (which does not appear in the ring voltage or voltage between the collector rings of the converter) upon the star, or diametrical voltage.

The first method can be used only for lowering the direct current voltage.

The second method can be used for raising the direct current voltage as well as for lowering it, but is only used, to any extent, for the former purpose, since when this method is used for lowering the direct current voltage, commutation is impaired.

It is possible, by proportioning the relative amounts by which the two methods contribute to the regulation of the voltage, to maintain a proper commutating field at the brushes for all loads and voltages. Where this is not done, however, the brushes are shifted to the edge of the next field pole and into the fringe of its flux, thus deriving the commutating field.

Let t = intensity of the third harmonic in such a variable ratio converter, or rather that component of the third harmonic which is in line with the direct current brushes, and which therefore produces the voltage regulation, as a fraction of the fundamental wave; t is chosen as positive when the third harmonic increases the maximum of the fundamental wave (wide pole arc) and thus raises the direct current voltage, and negative when the third harmonic lowers the maximum of the fundamental, and therewith the direct current voltage (narrow pole arc).

λ = loss of power in the converter (friction and coreloss); this is supplied by the current, as fraction of the alternating input (assumed as 4 per cent. in the numerical example).

β = angle of brush shift on the commutator, considered as positive in the direction of rotation.

γ = angle of lag of the alternating current (negative for leading current).

a = angle of shift of the resultant field from the position at right angles to the mechanical neutral (midway between the pole corners of main poles and auxiliary poles), considered positive in the direction opposite to the direction of armature rotation, that is, positive in that direction in which the field flux has been shifted to get good commutation, as discussed in the preceding sections of this article.

Due to the third harmonic t, and the angle of shift of the field flux a, the voltage ratio differs from the normal by the factor:

$$(1+t)\cos a$$

and the ring voltage of the converter is therefore:

$$E = \frac{E^0}{(1+t)\cos a} \qquad (3)$$

Hence from (1):

$$E = \frac{E_0 \sin\frac{\pi}{n}}{\sqrt{2}\,(1+t)\cos a} \qquad (4)$$

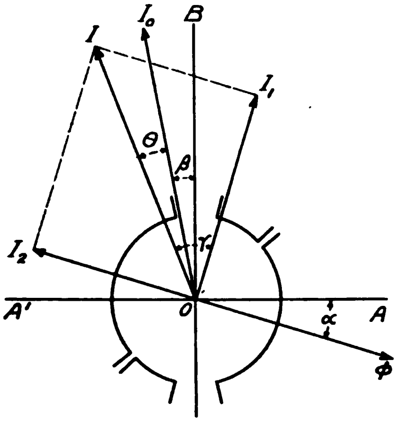


Fig. 18

and the energy component of the ring current (neglecting losses), corresponding to the direct current output, is, from equation (2):

$$I^1 = I^0\,(1+t)\cos a$$

$$= \frac{I_0\sqrt{2}\,(1+t)\cos a}{n\sin\frac{\pi}{n}} \qquad (5)$$

Due to the loss λ in the converter, this current is increased by $(1+\lambda)$ in a direct converter, or decreased by the factor $(1-\lambda)$ in an inverted converter.

The alternating *energy current* is therefore:

$$I_1 = I^1\,(1+\lambda)$$

$$= \frac{I_0\sqrt{2}\,(1+t)\,(1+\lambda)\cos a}{n\sin\frac{\pi}{n}} \qquad (6)$$

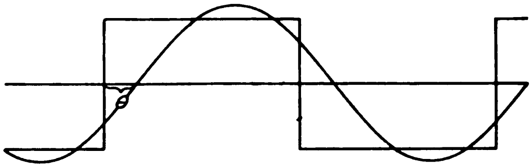


Fig. 19

where λ may be considered as negative in an inverted converter.

With the angle of lag γ, the *reactive current* is

$$I_2 = I_1 \tan\gamma$$

and the *total alternating ring current:*

$$I = \frac{I_1}{\cos\gamma}$$

$$= \frac{I_0\sqrt{2}\,(1+t)\,(1+\lambda)\cos a}{n\sin\frac{\pi}{n}\cos\gamma} \qquad (7)$$

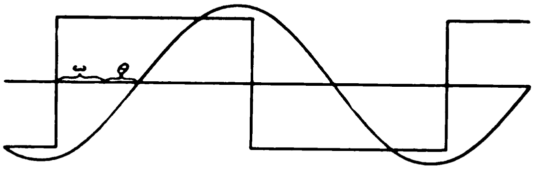


Fig. 20

Or, introducing for simplicity the abbreviation:

$$s = \frac{(1+t)(1+\lambda)\cos a}{\cos\gamma} \qquad (8)$$

the equation becomes

$$I = \frac{I_0\, s\sqrt{2}}{n\sin\frac{\pi}{n}} \qquad (9)$$

In Fig. 18 let $\overline{A^1OA}$ represent the center line of the magnetic field structure; then, the resultant magnetic field flux $\overline{O\phi}$ leads $\overline{OA}$ by angle $\phi OA = a$.

The resultant m.m.f. of the alternating energy current I_1 is $\overline{OI_1}$, at right angles to $\overline{O\phi}$; and the resultant m.m.f. of the alternating reactive current I_2 is $\overline{OI_2}$, in opposition to $\overline{O\phi}$, while the total alternating current I is $\overline{OI}$, lagging by angle γ behind $\overline{OI}_1$.

The m.m.f. of the direct current armature reaction is in the direction of the brushes, as represented by $\overline{OI}_0$, lagging by angle β behind the position $\overline{OB}$, where $BOA = 90°$.

Thus, from Fig. 18, the angle by which the direct current m.m.f. $\overline{OI}_0$ lags in space behind the total alternating m.m.f. $\overline{OI}$, is:

$$\theta = \gamma - a - \beta \qquad (10)$$

If the alternating m.m.f. in a converter coincides with the direct current m.m.f., the alternating current and the direct current are in phase with each other in the armature coil which is midway between adjacent collector rings, and the heating is thus at a minimum in this coil.

Due to the lag in space of the direct current m.m.f. behind the alternating current m.m.f., by angle θ, the reversal of the direct current occurs before reversal of the alternating current in the armature coil; that is, the alternating current lags behind the direct current by angle θ in the armature coil which is midway between adjacent collector leads, as shown by Fig. 19. In an armature coil displaced by angle ω from the middle position between adjacent collector leads, the alternating current lags behind the direct current by angle $(\omega + \theta)$, where ω is considered positive in the direction of armature rotation (Fig. 20).

The alternating current in armature coil ω can thus be expressed by:

$$i = I\sqrt{2}\, sin\, (\phi - \omega - \theta) \qquad (11)$$

Hence, substituting in (9):

$$i = \frac{2\, I_0\, s}{n\, sin\, \frac{\pi}{n}}\, sin\, (\phi - \omega - \theta) \qquad (12)$$

As the direct current in this armature coil is $\frac{I_0}{2}$, and opposite to the alternating current i, the *resultant current* in the armature coil ω is:

$$i_0 = i - \frac{I_0}{2}$$

$$= \frac{I_0}{2}\left\{\frac{4\, s}{n\, sin\, \frac{\pi}{n}}\, sin\, (\phi - \omega - \theta) - 1\right\} \qquad (13)$$

and the ratio of heating of the resultant current i_0 to the current $\frac{I_0}{2}$ of the same machine when used as a direct current generator of the same output, is:

$$\frac{i_0^2}{\left(\frac{I_0}{2}\right)^2} = \left\{\frac{4\, s}{n\, sin\, \frac{\pi}{n}}\, sin\, (\phi - \omega - \theta) - 1\right\}^2 \qquad (14)$$

Averaging equation (14) over one half wave, gives the relative heating of the armature coil ω, as:

$$\gamma\omega = \frac{l}{\pi}\int_0^{\pi} \frac{i_0^2}{\left(\frac{I_0}{2}\right)^2} d\phi = \frac{l}{\pi}\int_0^{\pi}\left\{\frac{4\, s}{n\, sin\, \frac{\pi}{n}} sin(\phi - \omega - \theta) - 1\right\}^2 d\phi \qquad (15)$$

Integrated, this gives:

$$\gamma\omega = \frac{8\, s^2}{n^2\, sin^2\, \frac{\pi}{n}} + 1 - \frac{16\, s\, cos\, (\omega + \theta)}{\pi\, n\, sin\, \frac{\pi}{n}} \qquad (16)$$

From this follows the local heating in any armature coil ω, and in the coils adjacent to the leads, by substituting $\omega = \pm\frac{\pi}{n}$; and also the average armature heating by averaging $\gamma\omega$ from $\omega = -\frac{n}{\pi}$ to $\omega = +\frac{n}{\pi}$.

The average armature heating of the n-phase converter is therefore:

$$\Gamma = \frac{2\, n}{\pi}\int_{-\frac{\pi}{n}}^{+\frac{\pi}{n}} \gamma\, \omega\, d\, \omega$$

or, integrated:

$$\Gamma = \frac{8\, s^2}{n^2\, sin^2\, \frac{\pi}{n}} + 1 - \frac{16\, s\, cos\, \theta}{\pi^2} \qquad (17)$$

This is the same expression as was found for the average armature heating of a converter of normal voltage ratio, when operating with an angle of lag θ of the alternating current, where s denotes the ratio of the total alternating current to the alternating energy current corresponding to the direct current output.

(To be Continued)

ELECTRIC DRIVE IN RAILROAD SHOPS

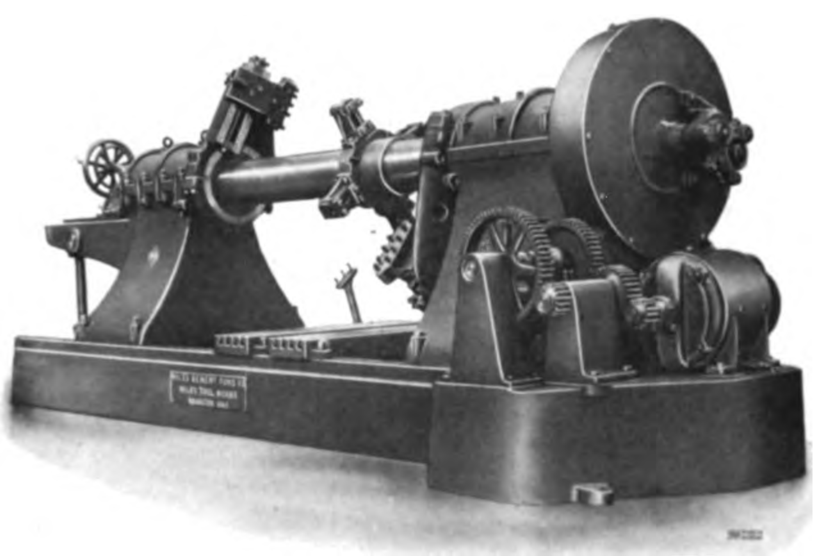
By John Liston

The theoretical advantages inherent in electric drive as compared with mechanical drive have long been conceded by the engineers of railroad shops, and all recent shop construction has been designed with a view to the utilization of electric power through either individual or group drive, or a combination of both forms.

In many cases, however, the complete electrification of old shops has been delayed on account of the heavy investment represented by the old plant and the natural disinclination of the financial management to relegate high priced machinery to the scrap heap, adding at the same time the burden of new construction and installation charges. Under these conditions the method of driving the larger machines by individual motors, and the smaller ones in groups by means of motors belted to short lengths of overhead shafting, has frequently been adopted as a compromise, which arrangement insures many of the benefits of motor drive with a minimum of additional outlay.

This combination eliminates many of the evils of purely mechanical drive, doing away to a large extent with the losses involved in the transmission of steam from the central station, through long lines of piping, to the engines in different buildings; reduces the friction losses in shafting and belting, and renders possible the use of electrically driven cranes. Furthermore this arrangement insures a minimum consumption of power in the operation of individual machines or groups, when these are used intermittently.

About eight or ten years ago, when motor drive was first generally adopted, the electrical and mechanical construction of the motors was bulky and crude as compared with the modern product, and it was impracticable in many cases to mount a motor of sufficient capacity on the headstock of a lathe, or to suspend it from existing ceiling beams; while if it was belt connected to a machine, it frequently occupied valuable floor space.

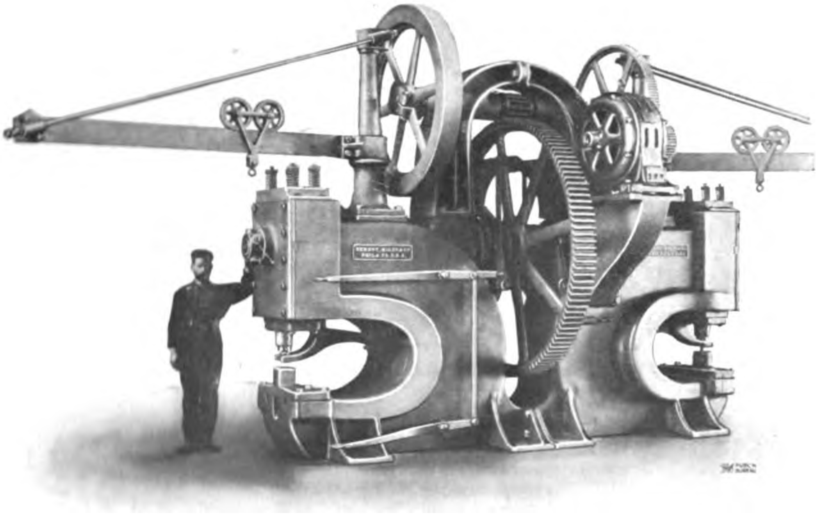


Cylinder Boring Machine Operated by 12 1/2 h.p. CR Variable Speed Motor

A glance at the accompanying illustrations will show that, in view of the compact construction of modern General Electric motors, these disadvantages no longer obtain, and this fact is emphasized by the readiness on the part of manufacturers of machine tools to design and construct their apparatus for independent motor operation.

Even the smallest machines can be equipped with individual motors, arranged for ready control, and the additional investment involved in their adoption will be offset in a relatively short time by increased production and low cost of operation. The ideal modern railroad shop, with all overhead shafting and belting eliminated and every machine capable of independent operation, can now be economically realized.

Comparing "group drive" with "independent drive," we find that, aside from certain applications in driving small groups of constant speed machines, the former has only one tenable point of superiority; *i. e.*, a lower first cost. On the other hand, group drive involves the retention of a considerable amount of overhead shafting, with its obvious friction losses; it does not permit of ready or gradual changes in speed, and the amount of power consumed by any given machine in a group is practically indeterminate.



Combined Punch and Shear Operated by a 20 h.p. Form K Induction Motor

In the average railroad shop, the first cost of "independent drive" will be about 15 per cent. in excess of that of "group drive"; the adoption of the former will, however, more than offset this additional expense by reason of the following advantages:

Increased Output

This is insured by the ability to control the speed of individual machines, and by permitting the general shop layout to be so arranged as to provide for the most efficient sequence of operations; thereby avoiding the re-handling of work with its attendant labor charges, and the congestion or injury of material. The present high cost of labor renders the question of minimizing the re-handling of materials an important factor in the cost of production.

For variable speed work, General Electric motors of special design can be provided for any speed variation up to and including a ratio of 4 to 1, and the economy rendered possible by their use was graphically illustrated by two diagrams which appeared on pages 233 and 234 of the April, 1908, number of the REVIEW. These diagrams showed the comparative time consumed by a belt-driven and a motor-driven lathe in facing a 72 in. cast-iron disk. The motor-driven tool performed the work in 52 per cent. of the time required by the belt lathe, notwithstanding the fact that the time lost in shifting the belt from one pulley step to another on the mechanically driven lathe was not considered. It is obvious that a constant cutting speed such as was obtained by the individual motor drive would otherwise have been impossible.

Saving in Fuel

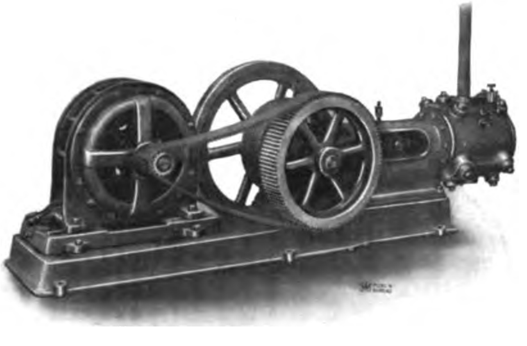
The frictional loss in the average railroad shop using mechanical drive amounts to from

20 to 60 per cent. of the total power, and while group motor drive reduces this to some extent, there still remains a considerable loss which varies with the length of the countershafts. The amount of fuel saved by the employment of independent motor drive will, of course, depend upon the extent to which group motor drive has been used, and the general conditions existing in the particular shop under consideration.

Saving in Labor

The retention of overhead shafting necessitated by group drive involves a loss of time in putting a machine in service, due to the shifting or replacing of belts on line shaft pulleys; and this work must be practically repeated for every change in speed required during operation. It is conservatively estimated that in the average railroad shop a machinist wastes about 20 minutes per day in these tasks, normally incidental to group drive.

In addition to this, there is the expense of repairing friction pulleys, lacing belts, etc., which is almost wholly avoided by the use of independent drive, even when direct motor connection is not feasible and short belts are used between the motor pulley and the machine.

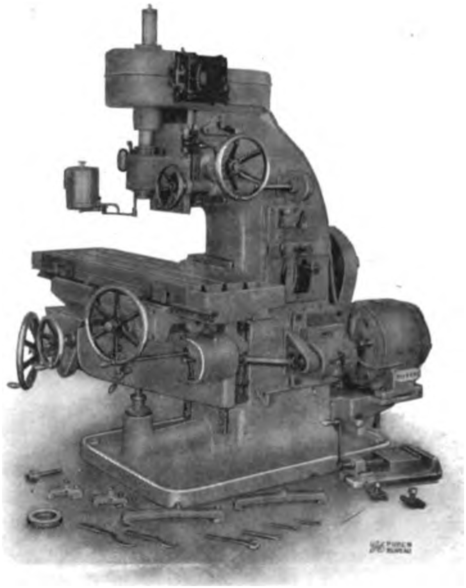


Chicago Pneumatic Tool Operated as an Air Compressor Driven by a 15 h.p. Form K Induction Motor

The annual expense represented by these labor losses should be carefully considered in comparing the merits of group and independent motor drive.

Reduction in the Size of Power Plant

It is obvious that the elimination of a large percentage of the friction loss by the use of independent drive will insure a given effective output with a smaller power plant than when group drive or purely mechanical drive is used. The writer recently visited a plant which, about a year ago, was changed over from mechanical to electrical drive, and it was found that a total capacity of 1700 h.p. in motors would do more work than was formerly performed by engines of 2250 h.p. It is evident, therefore, that the reduction in frictional losses will be directly proportional to the extent to which the independent system of motor drive is adopted.



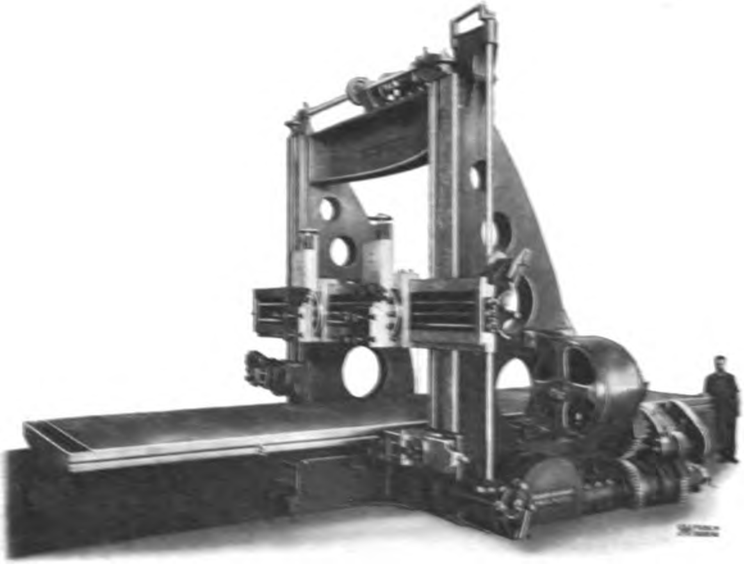
Milling Machine Operated by a 3 h.p. CR Variable Speed Motor

Unhampered Location of Machinery

Efficient machine shop design is frequently hampered when mechanical or group motor drive is used, from the fact that overhead shafting and belting complicates the operation of cranes, hoists, etc., limits production by interfering with the rapid re-handling of parts between successive operations, and, furthermore, increases the liability of accidents. These points are of especial importance in railroad shops where the time required for construction or repair work is often a standard by which their general efficiency is judged.

In this connection the use of direct connected motor driven portable tools is worthy of serious consideration, as their use will frequently allow two or more operations to be carried on simultaneously on a single piece of work. These tools can be readily transported to any desired location in the shop by means of overhead cranes, thereby obviating the necessity of rehandling and readjusting heavy parts.

The General Electric Company has given special attention to the design and construction of portable motor driven tools, and bears witness to a firm belief in their value by using them liberally in its own shops.



Planer Operated Through Pneumatic Clutches by a 50 h.p. Motor

The use of independent motor drive insures a clear space overhead for the operation of cranes and hoists, while the elimination of long lines of shafting and belting adds noticeably to the lighting of the shop during the day, and avoids troublesome shadows when artificial illumination is used.

Reduction of Maintenance Cost

The present price of double belting averages about $1.50 per sq. ft., so that in a shop using either mechanical or group motor drive, the purchase, repair and replacement of belts involves an almost continuous expense, which adds materially to the cost of production. Added to this is the necessity at irregular intervals of lining up the overhead shafting and replacing pulleys or bearings.

The utilization of independent motor drive, even if the motors are not direct connected, will greatly reduce the general maintenance costs, and in the average railroad shop the saving will amount to at least 50 per cent. of the total belting charges.

Ability to Economically Operate a Single Machine Overtime

Perhaps the most striking illustration of the economy of independent motor drive is given when, for any reason, a single machine is to be operated overtime or on Sundays. In this case the expense of operating the machine, if the current is obtained from an outside central station, is incurred only while the machine is actually in service; or, if the shop maintains its own generating plant, only a portion of it need be kept in operation. This is in marked contrast to the conditions existing in mechanically driven or group driven shops, where the operation of a single machine would call for the expenditure of approximately sufficient power to drive either an entire section of the plant or a group of machines.

Reduction in Cost of Building

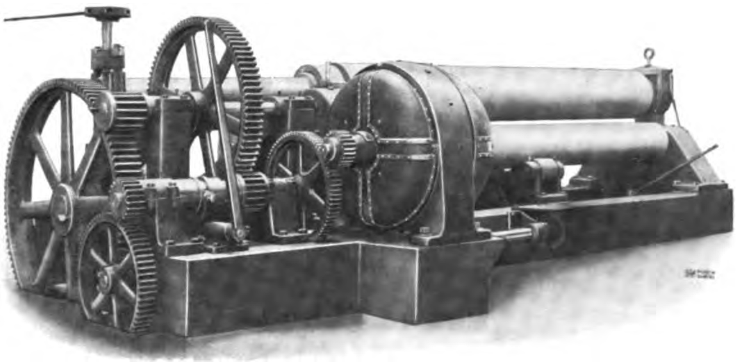
It is obvious that, with the elimination of overhead shafting and its numerous hanger bearings, the roof trusses and ceiling beams can be so designed as to reduce somewhat the usual cost of building. From available data, this saving has been estimated to amount to about 5 per cent. of the total cost of constructing the average railroad shop. In addition to this, the machinery can be obtained at a lower figure, as machine manufacturers will charge less for machines not supplied with countershafts. Finally, by the use of independent motor drive, cleanliness and safety are assured in general shop conditions, together with a marked improvement in appearance not otherwise obtainable.

From the foregoing outline of conditions affected by independent and group drive, it is evident that in spite of the lower first cost of the latter system, it is not the most economical form for electrically equipped shops. Leaving out of consideration altogether the general convenience and increased production obtainable by means of independent motor drive, in the average railroad shop the saving in operating and maintenance charges alone will offset the higher first cost in about two years.

Alternating Current vs. Direct Current

The electrification of any railroad shop inevitably brings up the question as to whether alternating or direct current, or a system combining the two forms, will insure the highest all-round efficiency. In the past, the simplicity of the direct current system and the ready speed control obtained by the weakening of the field of direct current motors, has frequently resulted in the adoption of a direct current system throughout. In a large majority of cases, however, this is not the best solution of the problem, for the following reasons:

In the average railroad shop, approximately 75 per cent. of the power required will be used for the operation of constant speed machinery and for lighting, and for constant speed work the induction motor as developed by the General Electric Company is ideally constructed. Comparing it with direct current motors of the same capacity, it is more compact, has fewer parts, does not involve the use of a commutator, operates at practically constant speed under varying loads, and will withstand heavy overloads for short periods without serious heating. It is light in weight per horse-power, can be readily started, and will continue running indefinitely without other attention than lubricating and, if exposed to dirt or dust, an occasional cleaning.



Large Bending Rolls Driven by a 35 h.p. CL-B Compound Wound Motor

For the boiler shop, blacksmith shop, woodworking shop, and in some instances, in operating cranes, planers, transfer tables, hoists, etc., where great variations in speed are required, the best results can be obtained by the use of series or compound wound direct current motors.

In order, then, to render fully available the advantages of electric drive, the power plant of a railroad shop should consist of A.C. generators driven by prime movers selected to meet local conditions. By the use of A.C.–D.C. motor generator sets, the highest individual efficiency can be obtained for both constant and variable speed machines, and the selection of illuminants can be made without regard to the character of the current required for their operation.

If the foregoing suggestions are carefully considered when solving the problems of construction or reconstruction, the ideal modern railroad shop, utilizing to the fullest extent the manifold advantages of electric drive, can be attained.

INFLUENCE OF WAVE FORM OF E.M.F. ON CORE LOSS AND EXCITING CURRENT IN TRANSFORMERS

PART III

BY L. T. ROBINSON AND O. HOLZ

GENERAL ELECTRIC STANDARDIZING LABORATORY

The theoretical considerations underlying the relations between wave form of electromotive force, core loss, and exciting current have been given in Parts I and II of this article, appearing in the April and May issues of the REVIEW. Examples have also been made out to show the application of the formulæ; but as stated in the last paragraph of Part II, the examples were not taken from actual tests, but were chosen arbitrarily for the purpose of illustrating the manner in which the formulæ are applied. In what follows, reference is made to actual tests performed under commercial conditions, with ordinary portable instruments.

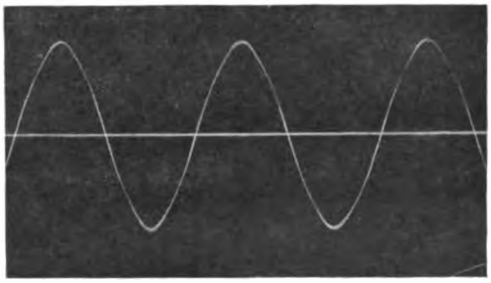


Fig. 2.

The tests were made on a 4 kw., 60 cycle transformer, having a high tension coil wound for 2080 volts and a low tension coil wound for 115 volts. Normal voltage was impressed on the low tension coil, and readings of volts, amperes and watts, and oscillograph records of impressed voltage, were taken simultaneously, the 2080 volt winding being left open.

First, a separation test for eddy current losses was made by running the alternator at speeds corresponding to 60, 50, 40, 30, 20 and 15 cycles, using a voltage in each case proportional to the frequency so that a density equal to that at 60 cycles was always obtained, and observing the wattmeter readings. The losses thus found were divided by the corresponding frequencies and plotted as ordinates, with cycles as abscissæ. A straight line drawn through these points cut the axis of ordinates at 44.43 watts, when the total loss amounted to 53.17 watts at 60 cycles; that is, the eddy current loss was found to be 8.74 watts at 60 cycles.

The total core loss was then measured for five different waves of e.m.f. (Figs. 2, 3, 4, 5 and 6).

The data tabulated below give the total core loss, the power-factor, the hysteresis loss, the form-factor of e.m.f. wave, and the calculated hysteresis loss. The wave of Fig. 2 is almost exactly a sine wave, while Figs. 3, 4, 5 and 6 show waves of various distortion; that of Fig. 3 is slightly flat-topped and that of Fig. 6 is decidedly peaked.

TABLE I

Wave	Total Core-loss (Watts)	Power-factor	Hysteresis Loss (Watts)	Form Factor	Coreloss Calculated for Sine wave (Watts)	Per Cent. Diff. Between Observed and Calculated Values
Fig. 2	53.17	27.7	44.43	1.11	53.17	
Fig. 3	53.32	27.4	44.58	1.105	53.04	0.245
Fig. 4	49.67	29	40.93	1.166	52.94	0.432
Fig. 5	51.82	29.7	43.08	1.126	52.54	1.2
Fig. 6	46.52	29.3	37.78	1.208	51.94	2.3

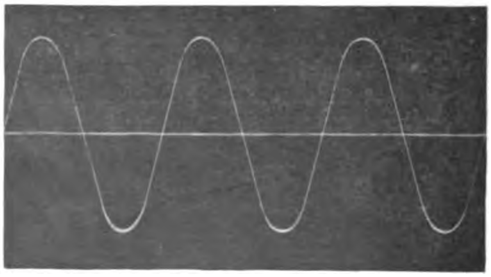


Fig. 3.

From this we see that the total loss with the peaked wave of Fig. 6 is $\frac{53.17 - 46.52}{53.17}$ or 12.5 per cent. less than that with the sine wave of Fig. 2; and when taking the loss as found by test for wave of Fig. 6 and correcting it for sine wave, we obtain a value within

2.5 per cent. of the observed value. This result is as close as can be expected for tests of this nature, which include the taking of the wave form and the calculation of the form-factor, the calculation of the hysteresis loss being based on the assumption that it varies according to the 1.6th power law.

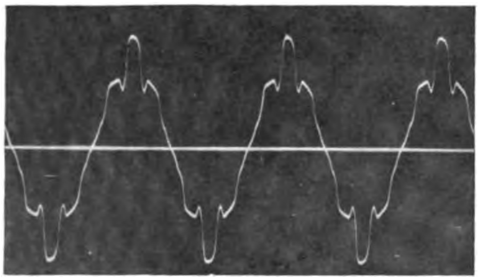


Fig. 4.

The result proves that a knowledge of the form-factor and the amount of eddy current losses in a transformer is sufficient to enable calculation of the total losses for different wave shapes.

The various observed exciting currents, and their components as calculated from the observed power-factors, are given in Table II.

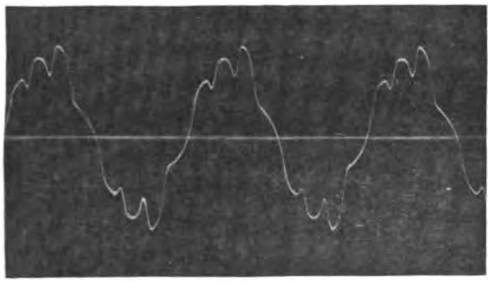


Fig. 5.

TABLE II

Wave	I_t Total Observed Exciting Current	$I_e = I_t$ (obs.) × Cos ϕ (obs.)	$I_m = I_t$ (obs.) × Sin ϕ (obs.)
	Amperes	Amperes	Amperes
Fig. 2	1.67	0.462	1.605
Fig. 3	1.69	0.464	1.626
Fig. 4	1.49	0.432	1.425
Fig. 5	1.515	0.451	1.448
Fig. 6	1.38	0.404	1.32

Now, calculating I_e for sine wave, by dividing loss in watts obtained from Table I, column headed "Core loss calculated for sine wave," by 115 volts, we get:

TABLE III

I_e calculated for sine wave.

Wave	Amperes
Fig. 2	0.462
Fig. 3	0.462
Fig. 4	0.461
Fig. 5	0.4575
Fig. 6	0.450

It remains to compute the magnetizing current for the sine wave. For this purpose a saturation, or B and H curve was taken of the transformer by means of the ballistic galvanometer, the high tension coil of the transformer being used for magnetizing the core and the low tension coil for exploring the fluxes. (See Fig. 7.)

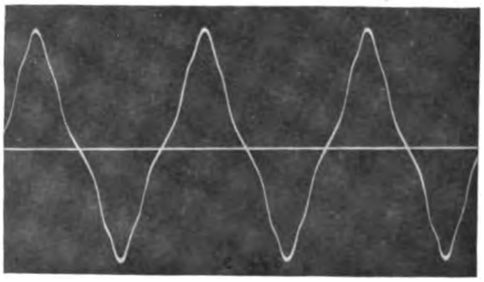


Fig. 6.

The form-factor, as shown in the May number of the REVIEW, page 280, gives us the density, and from this and the curve the following table has been compiled.

TABLE IV

Wave	$\underline{B}$ calculated from form factor	μ	H. from curve
Fig. 2	10500	1560	6.73
Fig. 3	10550	1540	6.85
Fig. 4	10000	1740	5.75
Fig. 5	10360	1610	6.44
Fig. 6	9640	1860	5.19

Now, from Table II, column headed I_m, and from Table IV, column headed H, we get, according to equation (13):

TABLE V

I_m calculated for sine wave.

Wave	Amperes
Fig. 2	1.605
Fig. 3	1.6
Fig. 4	1.67
Fig. 5	1.51
Fig. 6	1.71

Now, adding vectorially I_e of Table III and I_m of Table V at right angles, we get:

TABLE VI

I_t calculated for sine wave.

Wave	Amperes
Fig. 2	1.67
Fig. 3	1.67
Fig. 4	1.73
Fig. 5	1.59
Fig. 6	1.77

The wave of Fig. 6 will be chosen for comparison, since it was the one requiring the largest correction and showed the maximum difference between observed and calculated values. The observed exciting current at peaked wave (Fig. 6) was 1.38, or 17.3 per cent. smaller than that at sine wave (Fig. 2): but calculating for sine wave of e.m.f., we find 1.77 amperes as the exciting current, that is, we have come within $\frac{1.77 - 1.67}{1.67}$, or 6 per cent. of the true value by computation.

The B and H curve of the transformer core is not always readily obtainable, and in the central station means are not usually at hand for obtaining this curve experimentally on any certain transformer, as was done in the present instance.

It is possible to arrive at the result in another way, as follows:

Working from the data already at hand, which was used in computing the core loss on sine wave, the transformer may be run on a voltage higher or lower than that for which it is intended. This voltage, E, should be that for which the transformer is built, multiplied by the ratio, $\frac{\text{form factor test wave}}{\text{form factor sine wave}}$

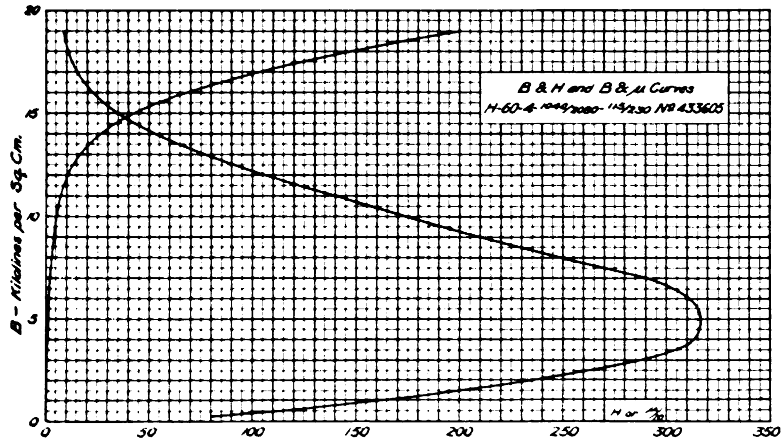


Fig. 7.

Using this voltage, the total current I_t is obtained and the watts W. The magnetizing current I_m is then computed from this measurement, and to this magnetizing current is added vectorially, at right angles, the energy current I_e corresponding to normal volts and cycles.

In obtaining the higher or lower voltage, E, needed for determining I_t, care should be used not to employ means for regulating that will distort the wave.

A large machine having an e.m.f. wave similar to that of the whole system should be disconnected from the mains and run for the test at the required voltage.

Certain waves may be produced, although usually not under operative conditions, which are much more distorted than any of those that have been considered, and which even cross the zero line at points between those corresponding to the frequency of the fundamental. The reasoning which has been given may be expanded to cover such cases, but the application is not always obvious. It is hoped that this part of the subject may be taken up again at some future time.

A FLOODED POWER PLANT

With the steadily increasing use of water power for the driving of electric generators, and the consequent location of power plants along the banks of rivers and canals, the liability of injury resulting to electrical machinery from floods is greatly augmented.

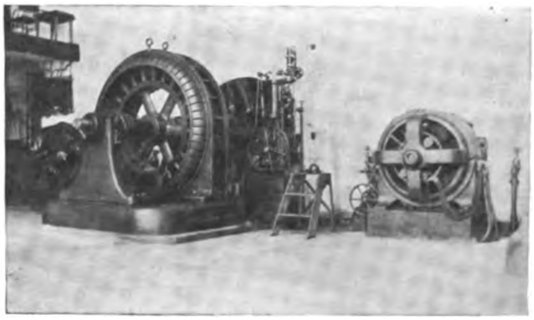
In equipping such plants, it behooves engineers and owners to select apparatus that has demonstrated its ability to withstand the damaging effects of water.

The following account of the flooding of the Gaffney Electric Manufacturing & Power Co., of Gaffney, S. C., speaks much for the superiority of the materials and methods employed in the insulation of the generators, transformers, exciters, etc., which are all of General Electric make. For the information contained therein, we are indebted to Mr. H. A. Parshall, operating engineer of the power plant.

Generator Room, Showing Generators Partly Submerged

On August 25th, at 3.30 o'clock in the afternoon, water entered the power house, completely flooding the generators and transformers. The two 125 kw. exciters were entirely submerged for 39½ hours. When the water finally commenced to fall, work of cleaning mud off the generators and transformers was started. This was accomplished with a hose, pressure being obtained from the dam. As soon as the bearings were uncovered, they were cleaned and oiled, and by nine o'clock on August 27th, one generator was running, the others being started as soon thereafter as they could be cleaned off and oiled. At 2 p. m. on the same day, the water having been fanned from the generator coils, the armatures of the generators were short circuited and the fields excited with low voltage from the exciters, until the armature current was raised to about 30 per cent. over full load value, thermometers being kept on the coils to see that the temperature did not rise above 80° C.

Somewhat more trouble was experienced in drying the field coils of the exciters. No difficulty was experienced in getting voltage, but when this was raised to normal, the field coils heated dangerously. The shunt winding was therefore disconnected, and the armature short circuited through the compound winding. By regulating the speed of the machines, any desired temperature of the field coils could be got, the armature heating about the same amount.



600 Kw. Generator, 125 Kw. Exciter

At seven o'clock on the evening of August 29th (75½ hours after the shut down), current at 2300 volts was sent to Gaffney, five miles distant. On September 2nd, during the early part of the afternoon, current was sent to Spartanburg, twenty-five miles distant, having been stepped up at the Gaffney substation from 2300 to 33,000 volts.

Transformer Room During Flood

The transformers are arranged in two banks, each bank consisting of three-1200 kw., 2300/33000 volt transformers. As soon as access could be had to these, the water, which amounted to as much as from fifty to one hundred and fifty gallons in each transformer, was drawn off. Sufficient barrels were found to hold the oil from one bank of transformers. The oil was run into these, and the heating of the transformer coils begun. To heat the coils, the secondaries were short circuited and enough current forced through the primaries to give the correct temperature. This drying process was continued for thirty-six hours. An iron tank which held 700 gallons was then procured; 12 street car heaters were put into this, and the oil from the transformers poured in. The oil was heated until it would stand a test of not less than 20,000 volts (break-down short intervals) on a 0.2 in. gap submerged in the oil.

After thus obtaining a satisfactory test of the oil, it was put back in the transformers, the temperature of the coils having first been adjusted to that of the oil.

THE ENERGY OF STEAM

PART II

BY J. W. KIRKLAND

Steam may expand gradually and do work by overcoming the resistance of an opposing surface, as the piston of an engine, or it may expand rapidly and do work upon itself. The latter kind of expansion may either result in superheating the steam, as in a throttle valve, or in imparting energy of motion (kinetic energy) to the expanded steam, as in the nozzle of an impulse turbine.

When steam is admitted to an engine cylinder, the effect, up to the point of cut off, is to drive forward the piston by virtue of the expansion of the whole volume of steam between the piston and the surface of water in the boilers and including the steam space in the boilers and in the pipes. The volume added by the displacement of the piston is, as a rule, insignificant as compared with the whole volume of steam, and the pressure upon the piston is, therefore, approximately constant during this part of the stroke. Fig. 1 is an indicator diagram of a simple engine taking steam from a boiler which maintains 70 pounds pressure at the engine. Not all this pressure is exerted upon the piston, owing to the friction in the valve port. The card shows that there is a loss of about 5 pounds pressure due to this cause. The point *a* is the cut-off point where the admission valve has closed entirely; the increased friction, or "wire-drawing," due to the diminished port area as the valve closes, is indicated by the dropping curve from the line of admission to the point of cut-off.

Apart from the loss due to wire drawing there is that of cylinder condensation. The temperature of a cylinder is always lower than that of the admitted steam, and this results in condensation in the early part of a stroke. It is not possible to calculate correctly the steam consumption of an engine by the volume displaced by the piston prior to cut-off. For example, in the case of the cylinder of which Fig. 1 is the indicator card, the steam consumption per hour as figured by piston displacement is 5500 pounds, while by test the consumption was 6800 pounds, or 25 per cent. more.

That portion of the curve between the points *a* and *b* is the expansion line of the steam. This may be nearly an adiabatic curve or it may depart quite widely from the adiabatic curve, depending upon the transfer of heat to or from the steam and upon the mechanical losses due to friction and leakage. The point *b* is that of release; that is, the point when the exhaust valve opens; the pressure at *b* is about 9.5 pounds absolute, while the back-pressure at mid-stroke, which may be assumed to be the pressure in the condenser, is about 3.5 pounds. The pressure at *b* is determined by the ratio of expansion permitted by the cylinder length.

If the cylinder were shorter, the steam would be discarded to the condenser at a higher pressure; if it were longer the steam would be expanded to a lower release pressure. But a great disadvantage in carrying the expansion too far in a single cylinder lies in the fact that it will then produce large cylinder condensation. The temperature of steam at the admission pressure shown in the card (Fig. 1) is 312 degrees, while the temperature corresponding to 9.5 pounds absolute is about 190 degrees. Since each end of a cylinder is alternately exposed to live and to expanded steam, it may be assumed to have a temperature midway between the two, or in this case 256 degrees. If the steam were expanded down to, say, 4 pounds absolute pressure, the mean temperature of the cylinder would be reduced to 232 degrees, and cylinder condensation on admission would be increased. While the steam is thus partially condensed on admission to a comparatively cold cylinder, it is partly re-evaporated later on beyond mid-stroke, at which time its temperature is lower than that of the cylinder and piston. But even if it were completely re-evaporated, it would only make up to a small extent for the initial condensation; for it returns to the state of steam having small available energy (due to low pressure and temperature); whereas, when originally lost it was steam of large available energy. It is quite usual to find the expansion curve on an indicator card fall below the true adiabatic curve early in the stroke and rise above it in the latter part of the stroke, due to the interchange of heat between cylinder walls and steam.

It is largely in order to prevent initial cylinder condensation that engines are made compound; that is, with two or more cylinders, the steam working first in a high pressure cylinder and then in a low pressure one. Another obvious advantage of compounding is that it secures the desired high expansion ratio with short stroke and permits operation at higher speed than would be possible with a very long cylinder.

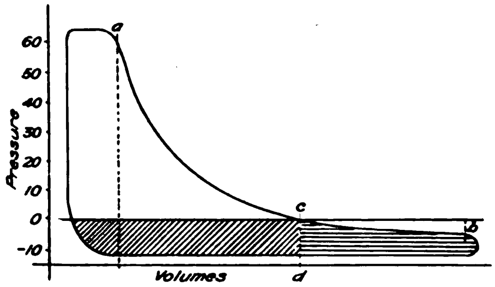


Fig. 2.

It should be borne in mind that the heat carried by the steam when the exhaust port opens is wasted. The farther the expansion is carried the less this loss will be. For instance, a pound of steam at 9.5 pounds absolute pressure, if worked to a vacuum of 3.5 pounds, is theoretically capable of doing about 50,000 foot-pounds of work, or 40 per cent. as much as it is able to accomplish between the limits of pressure shown by Fig. 1. A steam engine rarely exhausts at a lower pressure than 5 or 6 pounds absolute; a steam turbine, on the contrary, if of good design, permits the useful expansion of steam in its last stage to a pressure considerably lower even than 1 pound absolute.

Considering the effect of vacuum, as shown by the indicator card, it will be noted that the increased output of the cylinder can be divided into two parts. First, the increase due to relief of back pressure, which is indicated by the area cross-hatched with diagonal lines; and second, the increased area due to increased opportunity of expansion, represented by the area cross-hatched with horizontal lines. Some benefit would evidently be secured by condensing, even though the release pressure of the cylinder were considerably higher than it is; but any increase of release pressure is at the expense of the power obtainable by expanding the steam down to the condenser pressure. Suppose that instead of having an atmospheric pressure of 14.7 pounds above absolute vacuum, the cylinder were worked at an elevation such as to produce a pressure of 12 pounds (corresponding to about 6000 feet above sea level). The effect on the indicator card would simply be to lower the position of the atmospheric line to the dotted position shown in Fig. 2. The area of the card is not changed; the point of cut-off is not affected. As regards steam consumption and power, it is evidently immaterial where the atmospheric line is located. The cylinder is working between certain limits of pressure and temperature, and, being inanimate, is quite unconscious of the weather and barometer. A high altitude is, if anything, a little more favorable to steam economy than sea level, whether condensing or non-condensing. In a rare atmosphere the exhaust of a a non-condensing engine is at a slightly lower temperature, and there is, consequently, more available energy. For example, as between 165 pounds to 15 pounds, and 165 pounds to 12 pounds (all being absolute pressures) there is 8 per cent. of available energy in favor of the lower pressure. Exhausting to a vacuum at a high altitude is slightly more favorable than at sea level, because of less air leaks into the system and less work on the air pump. It is true that *relatively* there is less benefit in condensing at a great altitude than at sea level, but as regards actual economy of operation, as shown by the coal pile, altitude makes no difference.

When steam expands through a throttle valve there is no opportunity for it to lose heat by radiation or by transformation to mechanical work. Its total heat remains the same, therefore, at the lower pressure as at the higher, and the difference between the heat corresponding to saturated steam at the two pressures is represented by superheat due to throttling. For example, a pound of saturated steam at 150 pounds gauge pressure, expanded through a throttle valve to atmospheric pressure, will have, at the lower pressure, 46.7 B.t.u. more total heat than corresponds to saturation, and is superheated about 100 degrees Fahr. because of this excess heat.

It should be noted that although after throttling we have the same total heat in the superheated steam at atmospheric pressure as in the saturated steam at 150 lbs. pressure, we have nowhere near the same available energy, for the heat is at a much lower level of temperature and pressure. Throttling, therefore, is always wasteful of available energy.

Turbines

When steam is discharged through a suitably designed orifice, such as the nozzle of an impulse turbine, it expands adiabatically, and practically all of its available energy between the pressures on the two sides of the nozzle is transformed into kinetic energy. The mathematical expression for kinetic energy is $E = 1/2\ MV^2$, where E equals energy, M equals mass (or weight divided by acceleration due to gravity), and V equals velocity.*

Knowing the available energy due to adiabatic expansion, it is very simple to calculate the theoretical velocity. For example, if the pressure range is from 165 pounds to atmospheric pressure, the equation becomes:

135,000 (available energy of 1 pound of steam between these pressures)

$$= \frac{1}{2} \times \frac{V^2}{32.2}$$

$$\text{or } V = \sqrt{64.4 \times 135000} = 8.02 \sqrt{135000}$$

= (approximately) 2940 feet per second.

If the pressure range were from 165 pounds to 1 pound absolute, the velocity would be about 4000 feet per second

The function of an impulse type of turbine is to transform the kinetic energy of steam expanded in nozzles to useful work. A single stage turbine makes use of all the energy that it develops in one set of nozzles and on one wheel; for reasonable efficiency its wheel must have an extraordinarily high peripheral velocity, and therefore, in practice its speed of revolution must be very great. It is, in fact, so great that gearing of high ratio and most accurate design is necessary to permit the operation of even such high speed apparatus as electric generators.

Theoretically, the maximum work is obtained from a jet impinging upon a simple surface, when the surface moves in the direction and at one half the velocity of the jet. The reason for this is appreciated from the consideration that, if the surface were stationary, it would have no work done upon it, because there is no motion; if it moved with the same velocity as the jet, it would have no work done on it, because the jet would exert no pressure. The theoretical condition of maximum work is midway between these two extremes, or when the surface moves at one-half the velocity of the jet.

The Curtis turbine divides the available energy of the steam between suitable stages, and thus secures a steam velocity which can be used efficiently by bucket wheels of comparatively low velocity. Furthermore, there are two, or in some cases three, rows of moving buckets carried by the wheel of each stage, and the kinetic energy produced in the nozzle is abstracted only partially by the first row, the velocity that remains being transformed into work by the succeeding rows of buckets. The effect of this division is to reduce still further the bucket velocity necessary for good economy.

Considering the effect of a condenser upon a turbine, it is evident that it increases the available energy of the steam, and therefore gets more useful work out of each pound of steam used. There is no such consideration as the relief of back pressure as in the case of an engine: it is simply that steam, which if discharged at atmospheric pressure would be lost, is permitted to acquire velocity and do work between that pressure and the condenser pressure. Expanding between atmospheric pressure and one pound absolute, steam will acquire a velocity of 2790 feet per second, which is practically as great as the velocity acquired between 150 pounds and atmospheric pressure. This is another way of stating the fact that the available energy of steam below atmospheric pressure is about as great as from a reasonably high pressure to atmospheric pressure.

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* The derivation of this expression is from the definition of force as that which produces velocity. The relation expressed follows simply and necessarily from fundamental considerations and is explained in all text books.

It is only a steam turbine that can make efficient use of high degrees of vacuum. The kinetic energy of highly expanded steam can be transformed into work with very high efficiency, whereas to use such energy by gradual expansion, as in an engine cylinder, would require cylinder and valve areas which are quite impractical. It is due to this fact that the combination of an engine and a low pressure steam turbine, the latter taking steam at about atmospheric pressure after it has worked down expansively from high pressure in the engine, achieves such very economical results.

Condensers

A condenser is, in principle, a device for removing and wasting heat. The heat which it is called upon to absorb is the latent heat of the steam discharged from an engine or turbine; by absorbing this heat, it causes the steam to contract from the large volume which it occupies as steam at the discharge pressure, to the small volume which it occupies as water; the result of such contraction is a vacuum.

In the consideration of condensers, the conception of "heat balance" is very important; it is simply that all the heat abstracted from the steam must be accounted for by the heat added to the condensing medium, which is usually water. For example, if a pound of steam at one pound absolute pressure be condensed by being mixed with water, as in a jet condenser, it will give up latent heat equal to 1043 B.t.u. The temperature of the condensing water after mixture cannot be higher than that of steam at this pressure, which is 102 degrees Fahr.; so that if the water entering the condenser be at 70 degrees, each pound may absorb $102-70=32$ B.t.u. The amount of water necessary to condense each pound of steam is evidently $1043 \div 32 = 32.6$ lbs. The same result will be reached by an equation expressing the *total heat* of the steam and water before and after mixture; thus, if X be the pounds of water required per pound of steam condensed, we may write:

$$1113.1 + X\ (70-32) = (X+1)\ (102-32),$$

or solving, $X = 32.6$.

Since the discharge from an engine or a turbine is always a mixture of steam and water, it is evident that for accuracy we should take for this equation the proportion of the steam which remains uncondensed after expansion. As we may determine the amount of water theoretically necessary to condense steam at a certain temperature, it follows that, knowing the amount of water passed into a jet condenser and its temperature rise, we may calculate the number of heat units added to it, and from this, quantity of steam condensed. The wetness of the steam is readily determined by condensing a sample of it in a vessel containing a known quantity of water at a known temperature, and noting the increase in temperature corresponding to a determined increase in weight due to the added steam. The theoretical calculation of a surface condenser in which the steam and cooling water are not directly mingled is not quite so simple, because we have to consider the fall in temperature necessary to convey the heat through the tubes to the water. The discharged water is always at a lower temperature than that corresponding to the vacuum produced.

A condenser has not only to receive steam, but also the air which is carried by the water fed into the boiler, and that which may leak in and mingle with the steam at the joints or packings where the steam is at a lower pressure than atmospheric. Since air is not susceptible to condensation at the condenser temperature, it must be removed as a vapor. Furthermore, the air will contain a certain proportion of water vapor, which, owing to the presence of the air, cannot be condensed. Such air and water vapor must be removed from a condenser, either by a pump or equivalent means, in order that it shall not accumulate and destroy the vacuum. Various methods are used in practice for accomplishing this result. There is the dry air pump, which is simply an air compressor, and which takes in the attenuated air from the condenser because it produces mechanically a higher vacuum than exists in the condenser, and compressing it to slightly above atmospheric pressure, discharges it into the air. Or the air may be taken out mixed with the condensed water, either by a pump or by the velocity of the discharged water. The highest degrees of vacuum are usually secured by means of an independent dry air pump. It is important that the air removed be as cool as possible, and this is usually provided for by removing it in the immediate neighborhood of the incoming circulating water. Independent water fed coolers are often placed between the condenser and the air pump to further decrease the temperature and consequently the volume to be handled by the air pump.

Air pumps may be compounded with advantage (for reasons analogous to those relating to compounding steam engines); that is, they may be arranged to compress in two cylinders in series.

The condensed steam in a jet condenser is removed with the cooling water, either by a pump, as in the ordinary self-contained jet condenser, or by the suction due to a column of water of suitable length, as in a barometric jet condenser.

In a surface condenser, the condensed steam is usually removed by a pump which forces it into the *hot-well* against atmospheric pressure.

Feed water heaters are used for the purpose of realizing from exhaust steam heat which, without such a device, would have to be supplied by coal under the boiler. In theory, a heater is much like a surface condenser; that is, the heat added to the boiler feed-water is that of the steam condensed in the heater. Since the latent heat of one pound of steam at atmospheric pressure amounts to about 966 B.t.u., the amount of boiler feed water that can be heated to a certain temperature by means of it is easily calculated. For example, if the water is to be raised from 70 degrees to 200 degrees, 130 B.t.u. are required per pound, and, therefore, every pound of exhaust steam will heat $966 \div 130 =$ (about) 7.5 lbs. of feed water. Just as in the case of the surface condenser, the water must be sensibly cooler than the steam by which it is heated, to provide for the transmission of heat through the metal surfaces. About two hundred degrees is, therefore, the highest feed water temperature possible with an exhaust steam feed water heater. Additional heat is often supplied to feed water by economizers which make use of the waste gases coming from the boilers.

(To be Continued)

THE BAKING INDUSTRY

A GREAT FIELD FOR ELECTRIC MOTORS

By C. L. Watson,

Far back in the dim past, ages before the dawn of history, mankind began to make bread, and it has ever since been the staff of life. So necessary is it to our existence that it has become a symbol for all food. The cry for bread arouses our deepest emotions, and it has been the forerunner of some of the most momentous events in the history of our race.

The first bread of which we have any knowledge was simply grain, soaked in water, and pressed into rude cakes. These were dried in the sun or over a fire. This was the bread of the cave man, and as he ate it he glanced furtively around him, in sullen fear of his hereditary enemies, the animals.

Eventually, with the slow progress of civilization, the grain began to be mashed or ground between two stones. The resulting cakes were easier to digest than the cakes made from the water-soaked grain, and were more nourishing. This form of bread still survives, and may be found in many parts of the world. It is the daily food of thousands of people in Mexico, and in Scotland is known as "oat cakes" and "scones."

Leavened bread, or bread "raised" by the fermentation of yeast, is attributed by history to the Egyptians. They probably learned the process from some preceding civilization, all record of which is now lost. The Egyptians taught the Greeks and the Jews; the Greeks in turn taught the Romans, and the process has descended without any material change to the present day.

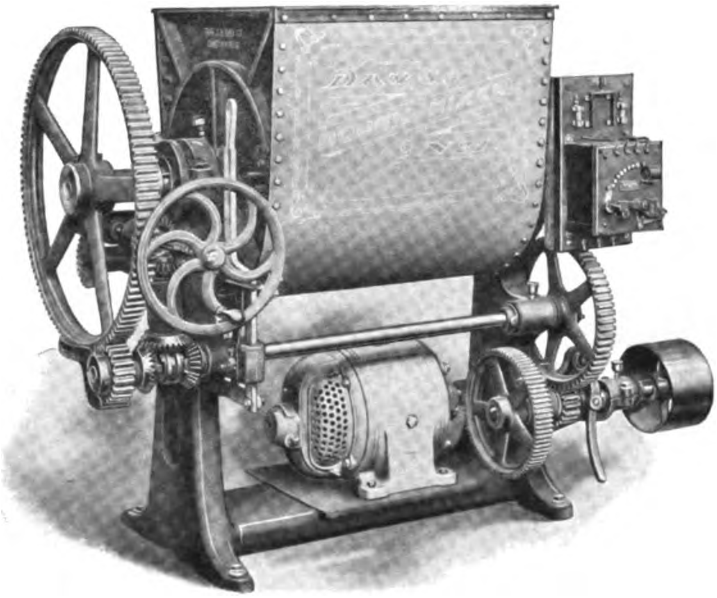
The making of bread is the oldest industry in the world, yet it has been the last to feel the influence of modern progress. Until some thirty years ago, bakers made their bread as it had been made for centuries, by punching or kneading the dough by hand. Other industries had been searchingly investigated by science, new methods had been introduced, and machinery had been invented to take the place of hand labor. In bread making, however, nothing of the kind had been done.

At the Centennial Exposition, in 1876, a mechanical dough mixer, in a very crude form, was exhibited in this country for the first time. The idea was taken up by several progressive men, and the many advantages of such a machine soon became manifest. Its introduction has been steady and rapid, although the majority of bakers have fought bitterly against it. It has also been greatly improved, and the dough mixer of today is a highly developed machine. It does better work than can be done by hand, its output is very large in proportion to the cost of the power required to operate it, and the results it produces are always uniform.

Following the lead of the dough mixer, other machines for the bakeshop have been invented, and bread may now be produced almost entirely by machinery. To understand how important these machines have become to the baking industry, let us analyze the different processes, or operations, in the making of a loaf of bread.

First, there is the mixing of the dough; this is done by the dough mixer. Second, there is the dividing of the dough into pieces the size of the loaves; this is done by the loaf divider. Third, there is the moulding of the loaves into proper shape; this is done by the dough moulder. Fourth, there is the special kneading or rolling of the dough for particular kinds of bread: this is done by the dough brake.

All of these machines have long since passed the experimental stage, and are now in practical daily use in a majority of the large bakeries of the country. They enable the baker to increase his output to very large proportions, and they have raised bread baking from its former position of an ordinary trade to the dignity of a great industry. They have also benefited the human race by increasing the production of bread and reducing the expense of producing it.



J. H. Day Company's Dough Mixer, Driven by G.E. 2 h.p. D.C. Motor
1 1/2 bbl. Capacity

Keeping pace with bread-making machinery are the machines for making cakes. All our cakes, by the way, had their origin in sweetened bread, and bread and cake machinery may be considered as very closely associated. There are now, in everyday use, machines for beating eggs, "pony" mixers for mixing cake and pie doughs, cake machines for placing the dough on the pans in various sizes and shapes, pie-rolling and pie-filling machines for the making of pies, and various other machines for special purposes.

Each of these machines, whether for the making of bread or the making of cakes, requires power of some kind to drive it. A steam engine or a gas or gasoline engine may be used, but nothing is so well adapted to the baker's needs as electricity. Electric motors may, in fact, be called the *ideal power* for the bakery. Their advantages are so numerous that only a few of them can be mentioned here.

In the first place, every machine can have its individual electric motor, and may be operated when desired. This is very satisfactory to the baker, for it is only on rare occasions that all of his machines are operated at the same time. Second, there is no expensive power plant for the baker to maintain, and no engineer is required to look after it. Even a very small steam, gas, or gasoline engine, looked after by the baker himself, is decidedly objectionable, for it takes up a portion of his time, and he must carefully clean his hands every time he touches it. Third, there is no dirt or dust of any kind, no engines to clean and no boilers to feed with coal. Electric power is the perfection of cleanliness.

This one fact alone is sufficient to induce every thinking baker to decide in favor of electricity. Modern sanitation demands that a bakeshop be kept clean, and it is to the baker's best interest to see that this demand is complied with.

As a fourth advantage in favor of electricity, the cost of installation and repairs is less than the first cost and maintenance of any other power. Bakers using General Electric motors report very little, if any, expense for repairs. As a fifth advantage, the cost for power is scarcely one-tenth the cost of doing the same work by hand, and there is a very decided saving over steam, gas or gasoline. Only the power actually used is paid for; and a large number of bakers, operating machinery in shops of ordinary size, have found the power cost of a motor driven dough mixer to range from one dollar to three dollars per month. At so slight an expense as this they are able to mix the dough for five hundred to one thousand loaves of bread every day.

The same work, done by hand, would require the services of at least one baker at twelve dollars to fifteen dollars per week, which would amount to fifty or sixty dollars per month.

The cost of operating any of the other machines is in proportion to the cost of operating the dough mixer, and is very low for the amount of the output. The expense for electric power in a completely equipped bakery of very large capacity does not often exceed twenty-five dollars per month. To do by hand the work that the machines in such a bakery will do is simply out of the question. A large number of bakers, twenty or thirty at least, would have to be employed, and the sum paid out for wages would be enormous.

The advantages of electric power in the bakeshop have become so well known to the manufacturers of bakers' machinery, that practically every machine of the kind now offered for sale can have electric motors directly connected. Of the dough mixers, the J. H. Day Company's Self-Contained "Day" Dough Mixer was the first directly connected electric dough mixer in the field. It has been steadily improved, and easily maintains its lead. The motor on this machine is placed underneath the mixing tank, and no more space is required than is taken up by the machine itself. The starting box is held by a bracket at the right of the tank, and at a convenient height. When equipped with a General Electric motor of sufficient size, the "Day" Self-Contained Dough Mixer is practically perfect, and it is difficult to see how such a machine could be improved upon.

Machines for other work, equipped in the same way, offer equally as many advantages when used for the purposes for which they are intended. It can be but a few years until every baker will be compelled, by competition if nothing else, to install at least a dough mixer, an egg beater, a "pony" cake mixer, a cake machine, and very likely a loaf divider and a dough moulder. There may be a few old-time bakers, like some old-time shoemakers, who will still cling to hand methods; but if there are, they will lead a precarious existence.

While the development in the baking business in the last thirty years has been remarkable, to close observers it seems only a beginning. Some means will eventually be found whereby a loaf of bread may be kept fresh and sweet for a week, or possibly longer. Meat and other food products are now shipped to all parts of the world, yet it is only in comparatively recent years that such a thing has been possible. It is not in the least visionary to predict that bread will eventually be shipped in the same way.

When the loaf of bread that will keep is produced, great bread factories will be established in all large cities, each factory baking possibly a million loaves each day. These will be distributed far and wide, and the baking industry will take its rightful place as one of the really great industries of the country. With so vast an increase in production will come a demand for machines that are not now thought of, or are only suggested. They will be as numerous as the machines in a shoe factory, or in a cotton goods mill, and electric motors will drive them all.

ROLLER BEARING TROLLEY BASE

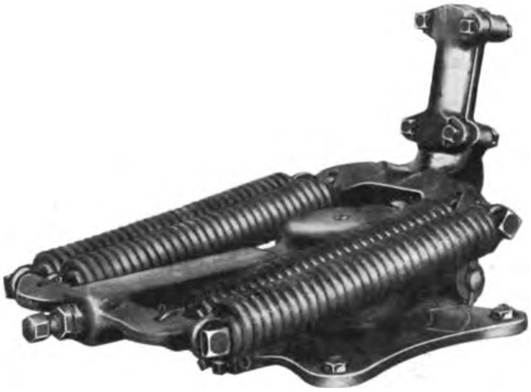
By John Liston

In the early days of electric traction the cars were operated on low tension circuits and at comparatively low speeds; the routes covered were also limited by the high cost of generating substations, and, as a result, designing engineers engaged in electric traction work devoted their attention to the problems of increasing motor efficiencies and the employment of higher potentials. These conditions naturally rendered the minor details of car equipment relatively unimportant.

The developments in the field of electrical engineering which rendered feasible the transmission of high potentials over long distances, improved motor efficiencies, and assured the reliability of operation of modern converting apparatus, enabled the electric railway to increase enormously its radius of action and to become in many cases a serious competitor of the steam railroad for interurban as well as local traffic.

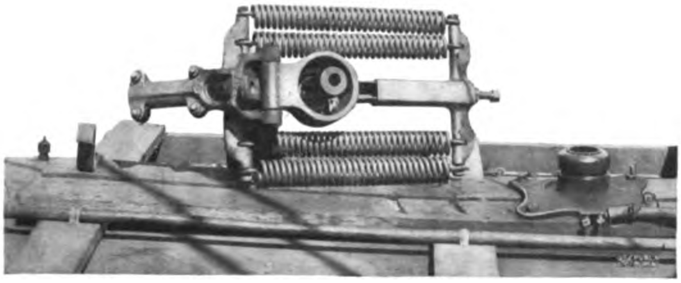
This extension of the electric railway entailed the necessity of maintaining accurate schedules; and small delays, until then of little consequence, occasioned by failures in the operation of minor portions of the car equipment, assumed serious proportions and of necessity had to be given greater attention than formerly. Accordingly, the work of perfecting the electrical and mechanical features of the auxiliary apparatus was taken up by the various electrical manufacturers, and the application and test of such apparatus was made a matter of study by the engineers of the traction companies.

While many electric roads use a third-rail system, the vast majority have adopted the overhead form of construction. Among the many detailed parts that are essential to smooth operation and uninterrupted service, few are more important than the trolley base, and great ingenuity has been displayed in the various forms which have been produced in the last few years. Many roads, especially those containing a large number of curves, have experienced considerable difficulty in maintaining schedules, due to frequent slipping of the trolley from the wire; this occurrence, in addition to the delay, often resulting in injury to the overhead system.



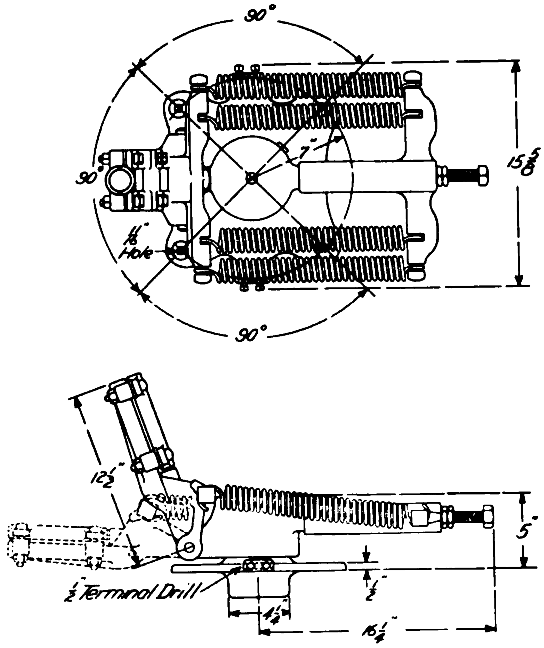
US-13 Roller Bearing Trolley Base

The ordinary trolley base, equipped with stud and sleeve bearing, does not prove to be sufficiently sensitive to allow the wheel and pole to readily follow the lateral and other irregularities of the trolley wire, thus causing sparking, which results in pitting of the wire and a gradual but general deterioration of the equipment.



Trolley Base after One Year of Service. Spring Frame Removed

In order to overcome the defects inherent in the ordinary forms of trolley bases, the General Electric Company has designed a roller bearing type, known as the US-13 trolley base. This is especially adapted for high speed interurban service, and is so designed as to be extremely sensitive and to insure a minimum wearing of the trolley wheel. It has an ample factor of safety in mechanical construction, all parts being carefully tested before being assembled, while at the same time the weight has been reduced to the minimum consistent with serviceability. The entire base, exclusive of the pole, weighs only 115 pounds.



Dimensions of Trolley Base

The bearing cup is provided with thirty-four steel rollers, and is so constructed as to be dust proof and oil tight, thus insuring a constant and uniform lubrication of the roller bearing. The oil inlet is located in the top of the bearing cup and is readily accessible.

Four extra heavy tension springs are used, and should it be necessary at any time to replace these, the bolt retaining the springs in place can be easily removed. The adjusting arm and slide are heavily ribbed, and are made of malleable iron. At the forward end of the base is located a single adjustment screw, by means of which the tension can be made to vary from 20 to 45 pounds pressure at the feeder wire.

An examination of the accompanying illustrations will show that the pole fulcrum is very low, and that the total height of the base (5 in.) is much less than that of other trolley bases in common use. This feature is of considerable importance on lines where the distance between the top of the car and the feeder wire is limited or varies, as is often the case under bridges and through tunnels.

The pitting of the rollers is practically eliminated by the good contact which exists between the center stud of the revolving element and the stationary base, the former resting firmly on the latter. A cushioned stop has been provided to minimize the possibility of mechanical injury.

The roller bearing base is so sensitive to changes in the angle of the trolley pole that sharp turns may be taken at high speed without danger of the trolley wheel leaving the wire.

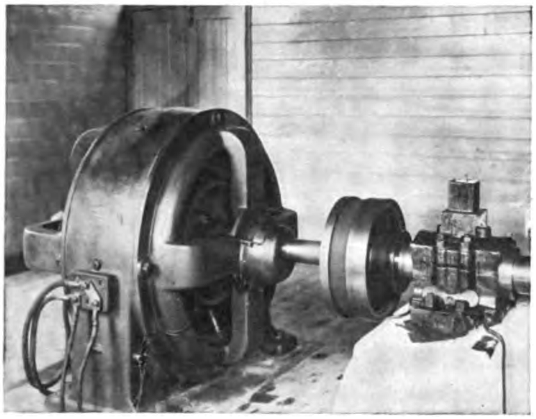
While this is a comparatively new device, it has nevertheless undergone severe tests in actual service, having been installed on cars operated by the Boston Elevated Railway Company, the Twin City Rapid Transit Company, and the Schenectady Railway Company, and in every instance the service records of the US-13 base show distinctively its superiority over the other bases with which it was operated for efficiency tests.

While the US-13 roller bearing trolley base was designed primarily for high speed interurban service, it has proved equally efficient for local traffic, and every initial installation has been followed by additional orders. The standard base accommodates poles 1⅝ in. in diameter, of a maximum length of 14 ft.

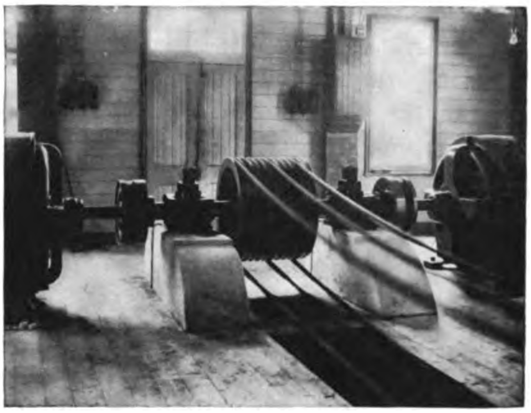
In conclusion, it may be stated that the records of operating costs show that wherever the US-13 roller bearing trolley base has been installed, there is, in addition to the saving in wear of trolley lines and freedom from interruption of service, a definite increase in economy of operation.

FAN EQUIPMENT FOR MINE VENTILATION

Within the last year, one of the largest ventilating fans south of the equator was installed at the Aberdare Mine in Australia. This fan is 11 ft. in diameter and 7 ft. wide, with double inlets each 7 ft. 6 in. in diameter. The shaft, which is of forged steel, is 9 in. in diameter and is provided with bearings of exceptional length. The normal speed of the fan is 300 r.p.m., with a capacity of 350,000 cubic ft. of air per minute at a pressure of 3 in. by the water gauge. If desired, the speed can be increased above normal.



105 h.p. Motor and Flexible Coupling



Arrangement of Motors, Couplings and Pulley

The fan proper consists of two sets of wings, inner and outer, the former being placed at an angle with the shaft, terminating at the center of the fan in special shape scoops which present more surface at that point than where they join the wings. This arrangement materially increases the volume of the intaken air.

The inclined inner wings lead the air across the fan, delivering it to the outer wings, by which it is discharged. These outer wings are set parallel with the axis of the shaft.

The fan is driven by two General Electric C.L.B. 6 pole, 105 h.p., 700 r.p.m. motors, direct connected to the shaft of the driving pulley through flexible couplings which permit of rapid uncoupling and coupling up in cases of emergency. The driving pulley is carried between two pedestals, on the outsides of which are located the motors and couplings, as may be seen by reference to the accompanying illustrations.

Owing to the fact that the fan was needed somewhat sooner than expected, the motors were put into actual service without being given the customary trial run. They have been in continuous operation ever since, and have not caused the slightest trouble.

PUBLICATIONS

RADIO-TELEGRAPHY

By C. C. F. Moncckton

D. Van Nostrand Co. 272 Pages Price $2.00

This volume briefly describes the principles and practice of Radio-telegraphy. The first two chapters treat of a few fundamental principles in electro-dynamics; chapters three and four dealing more specifically with electro-magnetic waves and their applications to wireless telegraphy. The remaining eleven chapters are mainly devoted to a description and explanation of the apparatus and measurements required.

It is difficult to set forth the general electrical theory underlying the application of Radio-telegraphy in four chapters, and, at the same time, give a sufficiently clear statement and resumé of the necessary facts for the proper understanding of the subject. This is true, even if the reader possesses some training in electrical science. It is, therefore, not surprising to find that the author occasionally fails to give clear explanations, due in part to a too condensed statement. The following examples may be cited: The definition of energy, namely, "the capability of doing work," rather obscures than illumines. The statement that "the period of vibration depends solely on the product of the self induction and capacity" is loose, and likely to make the reader think that the period is directly proportional to the product of these two quantities; whereas, it is proportional to the square root of this product. On page 33 the usual analogies are drawn between electrical and mechanical concepts to help an understanding of the meaning of electrical terms, without sufficient explanation being given of some of the quantities in question.

Notwithstanding these criticisms, the more important ideas have been summarized and, if carefully studied, sufficiently elucidated to give the reader an insight into the methods described in the latter part of the book.

The presentation of electric radiation is especially good and a clear picture is formed of the processes involved, without the aid of mathematics, which are, indeed, but sparingly used throughout the book, and then only in an elementary manner. In such a difficult subject, the fewer symbols the better.

Chapters five to nine inclusive describe wireless apparatus in some detail, and the reasons for, and advantages of the various forms used are clearly and fairly stated, no special consideration being given to any one system. This part of the book makes interesting reading to anyone unfamiliar with the subject. The points are easily remembered, because the facts are presented in logical form, the explanation of the methods used for "coupling" and their discussion being excellent. Chapter ten describes the principal instruments and measurements necessary, with a brief account of the underlying theory. The following three chapters describe radio-telegraph stations, using the Lodge Muirhead, Telefunken and Poulsen systems respectively. The question of portable stations for military purposes is considered in chapter fourteen, and the last chapter deals briefly with radio-telephony.

The book, on the whole, is lucid and well thought out, and one rises from its perusal feeling that the knowledge and insight gained in this fascinating subject have been considerable.

* * *

The following publications have been issued by the Publication Bureau of the General Electric Company during the past two months.

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3710 Edison Electric Decorative Lighting Outfits.
3715 Mercury Arc Rectifiers for Charging Telephone Batteries.
3725 Tungsten Lamps (Post Card).
4625 Parts of GE 67-A Railway Motor.
4627 Curve-Drawing Instruments for Alternating and Direct Current Circuits.
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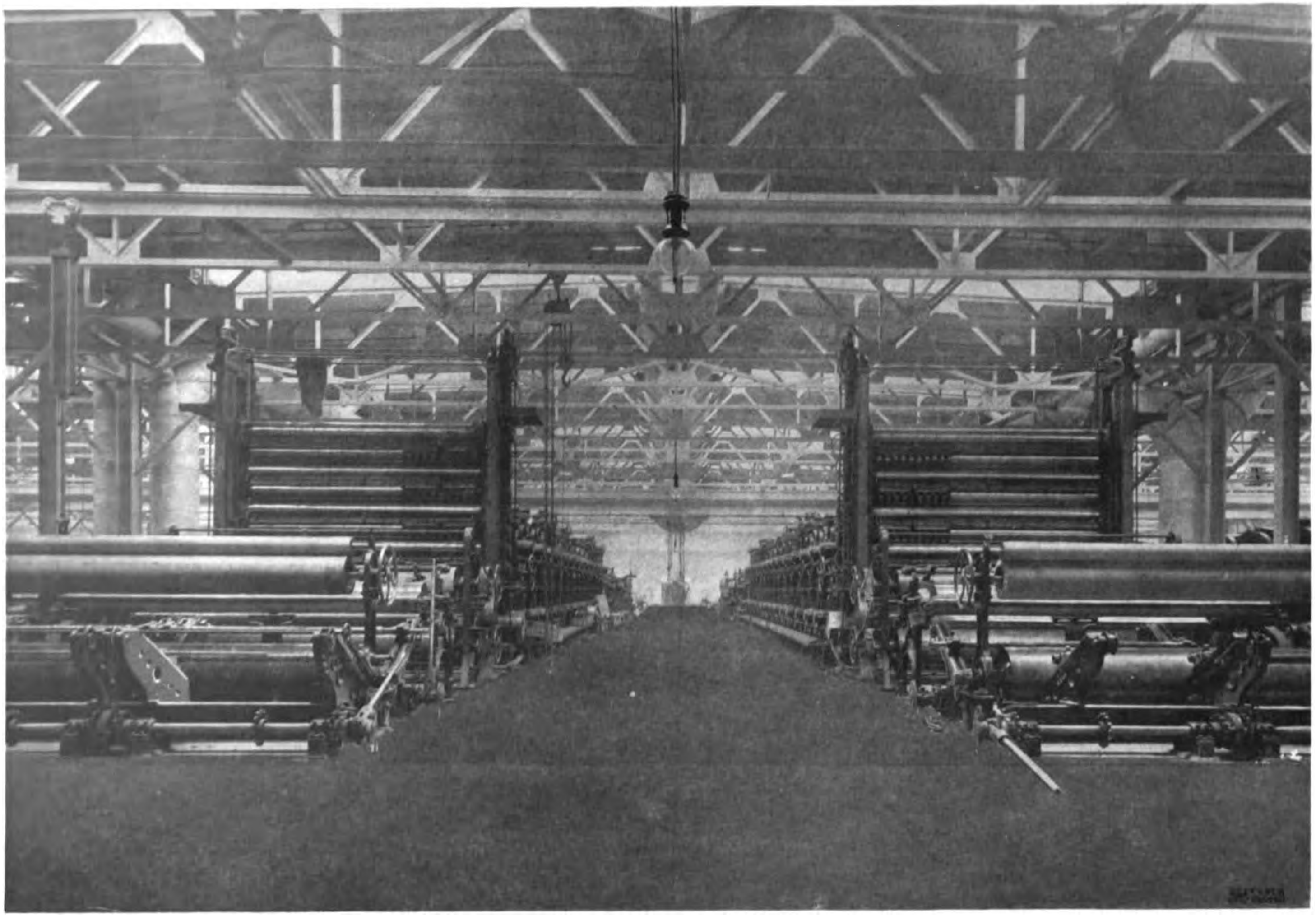

Motor-Driven Paper Machines

GENERAL ELECTRIC
REVIEW

SHORT CIRCUITS ON ALTERNATORS

The problem relating to excessive stresses on the shaft or windings of alternators, due to short circuits, is of considerable importance since the advent of low frequency turbine-generators. Mr. E. J. Berg's article dealing with this subject is, therefore, extremely timely. In it, he clearly shows the electrical interactions taking place in a machine under short circuit; how the electrical and mechanical constants affect the magnitude of current rush and short circuit torque, and the probable duration of their maximum value; the effect on the field flux due to transformer action between armature and field and that due to armature reaction; and, most important of all, the remedy to overcome dangerous stresses in the machine on short circuit.

The author shows that a sufficient remedy will be found by placing reactive coils in the generator leads, as close to the machine as practicable, or at the junction of the three windings in Y-connected generators. In the first case, the coils not only protect the alternator from mechanical stresses, but also, to a certain extent, damp out high frequency surges from outside; in the second case, they protect the generator mechanically, even if the short circuit occurs in the windings themselves.

The article is illustrated with oscillograms of the line voltage and armature and field currents at the moment of short circuit of a 5000 kw. turbine-generator operating at about one-quarter voltage. Interesting calculations are also made of the probable values of the short circuit current and torque under different conditions, with and without external reactance in circuit. These clearly show the large reduction of short circuit torque and current which is obtained in the former case.

The author concludes by giving the formulæ necessary for calculating the size and electrical constants of the reactive coils necessary, in terms of the alternator's rating, frequency, voltage, etc.

THERMODYNAMICS

The second installment of Dr. Steinmetz's lectures, completes his argument from which he deduces the laws of thermodynamics by means of general dynamical considerations. While pointing out that the result must only be taken as a tentative outline of a mechanical theory of thermodynamics, he nevertheless clears the ground for future work in this direction and clearly shows that it should be quite possible to derive all the thermodynamic relations in this manner. By so doing, the observed deviations of the behavior of gases from that of the perfect gas, due to the finite size of the molecule, disassociation, unequal atomic masses in the molecule, and the action of chemical forces within the molecule, etc., may be explained and their numerical values obtained.

Commencing with a central mass attracting two adjacent masses or satellites moving around it at unequal distances, the author shows that a progressive change in position will occur between the satellites, the nearer one moving faster than the one further off. Hence, they will separate when swinging round the central mass. If the satellites, however, are held together by mutual attraction, the quicker motion of the one over the other imparts a rotation of the two satellites around one another. Hence, Dr. Steinmetz deduces that, when molecules consisting of a number of atoms move around each other, a transfer of energy occurs; the energy of progressive motion is converted into energy of rotary motion,—intramolecular energy,—or *vice versa*. From this conception follows the idea that the chemical disassociation of the molecule is analogous to the evaporation of a liquid.

These considerations naturally lead to the calculation of the internal and external energies of a gas and the isothermal and adiabatic expansion curves.

The discussion of the equations for isothermal and adiabatic expansion are of the first importance, since the expansion of a gas left to itself when doing external work in a heat engine or when receiving external work in a compressor falls under the latter category, to a close degree of approximation.

As already stated in the last issue of the REVIEW, the subsequent articles by Dr. Steinmetz. on thermodynamics, will consider the Carnot and other heat cycles and their application to steam and gas engines and turbines. The article in the next issue will deal with Carnot and other cycles in a general manner.

ILLUMINATION

When the history of illumination is written, the early years of the twentieth century will stand conspicuous as an epoch of improvement, invention and development. Though many attempts were made to better the carbon incandescent lamp, little was accomplished commercially during the twenty years following its development by Mr. Edison in 1879. Squirted cellulose was substituted for bamboo filaments, and the process of "flashing" was invented; the efficiency was somewhat improved and the life increased; but of radical departure from the lamp as originally invented, there was none.

During the same period, despite the work of many able investigators, the commercial arc lamp also remained essentially unaltered —an arc between carbon electrodes.

With the opening of the new century, however, new inventions and developments followed each other in rapid succession; in incandescent lighting, the metallized filament, the tantalum lamp, and the tungsten, with the corresponding improvements in efficiency, life and quality of light; in the field of arc lighting, the magnetite, or luminous arc, and the flame arc.

Besides these fundamental changes in the illuminants themselves, many inventions have been made for the better utilization of the light, both for street lighting and interior illumination.

The article on Ornamental Tungsten Diffusers, appearing on page 74 of the present issue, describes one of the more recent developments in the latter field. These devices not only do away with the unpleasant glare inherent in a naked lamp, but diffuse a light of uniform intensity over a large useful area; they are, in addition, remarkably economical in the matter of current. The problem of securing scientificially designed electrical fixtures which will harmonize with the furnishings of finely appointed offices and stores is simplified by the invention of the ornamental diffuser.

In the field of street lighting, a comparison of standard present day methods was made by Mr. N. R. Birge, in the January issue. In the present number, Mr. G. N. Chamberlin discusses an important method not mentioned by Mr. Birge, namely, street lighting from interurban railway circuits. He points out that, with the introduction of A.C. transmission of relatively high voltage for railway operation, due to the size of wire necessary for mechanical strength, an excess of feeder capacity has become available and may advantageously be utilized for street lighting purposes; the use of the mercury arc rectifier for the arc circuits overcoming the difficulties that would arise from low frequency if the lamps were operated by the A.C. current.

The author also speaks of a new lamp that has been specially designed to operate on 25 cycle circuits, and the use of which obviates the necessity for the installation of a mercury arc rectifier (a description of this lamp will appear in the next issue of the REVIEW).

As Mr. Chamberlin points out, the apparatus necessary for street lighting from railway circuits requires little or no attention and the lighting load is a very desirable one for the street railway companies to secure, as is shown by the shape of a lighting station load curve.

He estimates the cost of installing and operating such a lighting system (using mercury arc rectifiers and luminous arc lamps), and shows that, under fair conditions, it should yield an annual dividend of about eighteen per cent. When commercial lighting is also undertaken, inasmuch as the additional apparatus, labor, etc. is not large, the profits on the increased investment are greater, and raise the dividends on the total investment to about twenty per cent.

The Magnetite Arc Headlight is also described in Mr. Chamberlin's article.

SHORT CIRCUITS ON ALTERNATORS*

By Ernst J. Berg

An important advantage of alternating current versus direct current, brought out in the early days of electric lighting, was that the generators could be short circuited without danger to the machines.

With the general introduction of 60 cycle instead of 125 cycle systems, and the building of large generators, it was realized that the stresses on windings and shaft at the time of short circuit were greater for the lower frequency, yet well within the limit of safety, and that there was still little liability of damage resulting to the generators.

With large engine-driven 25 cycle generators difficulties were at times experienced, and in the design precautions were taken that the end connections of the windings were securely supported.

Finally, with the introduction of low frequency turbo-generators the conditions imposed by short circuits were the most serious that the designing and operating engineer has had to deal with.

In order to understand this, it is desirable to briefly outline what takes place when an alternator is short circuited.

The current flowing depends upon three factors; namely, the resistance; the reactance, or true self induction of the circuit; and the armature reaction or the magnetizing or demagnetizing effect of the armature current on the field. The torque on the winding and shaft is proportional to the armature current, the field strength, and the power factor of the circuit. The *resistance* is, of course, readily determined. It is, in the case of a "dead" short circuit at the generator terminals, the resistance of that part of the armature winding which is short circuited. It varies with different machines, but may be assumed as 1 per cent.; that is, if no other factors entered into consideration at the time of short circuit, the current flowing would be 100 times the full load value.

As stated above, the torque produced by a given current is proportional to the current, the field strength, and *cos* ϕ, where ϕ is the angle between the current and field. Since at the first instant the field strength is not affected, and since we have assumed an armature having resistance only, and therefore current in phase with the field flux, or *cos* $\phi = 1$, we get a torque on shaft and winding of one hundred times the full load value.

The *reactance* in the circuit depends upon the arrangement and number of electrical conductors around the periphery of the armature, and upon the frequency of the circuit. The method of determining this factor is rather intricate and would not properly belong in this paper; suffice it to say that it is proportional to the frequency and square of the number of conductors per slot, and to a factor which depends upon the shape of the slots and their number.

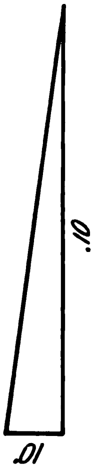

Fig. 1

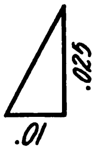

Fig. 2

In a general way we might say that the shape of the slots is similar in engine and turbine driven units, the number of conductors per slot for a given current being also about the same; but the number of slots is much less in the turbine type, the reactance being therefore almost proportionately less. As a matter of fact, the reactance is practically inversely proportional to the peripheral speed of the armature. With an engine driven alternator the reactance might be 10 per cent.; that is, the short circuiting current, were there no other limiting features, would be ten times the normal. With the turbo-generator, where for the same output the number of slots might be only one-quarter of that in the previous case, the reactance may be only 2.5 per cent., and therefore the short circuit current forty times the normal.

Assume, as in the previous case, that the resistance is 1 per cent.; then, for the engine driven unit, the power factor of the short circuited system would be determined by Fig. 1.

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* Paper read at Annual Meeting of Association of Edison Illuminating Companies.

$$\tan\phi=\frac{0.10}{0.01}=10;\ \text{and}\ \phi=84.5°$$
$$\text{and}\ \cos\phi=0.09$$

In the case of the turbo-generator we have from the diagram (Fig. 2)

$$\tan\phi=\frac{0.025}{0.01}=2.5;\ \phi=68°$$
$$\text{and}\ \cos\phi=0.37$$

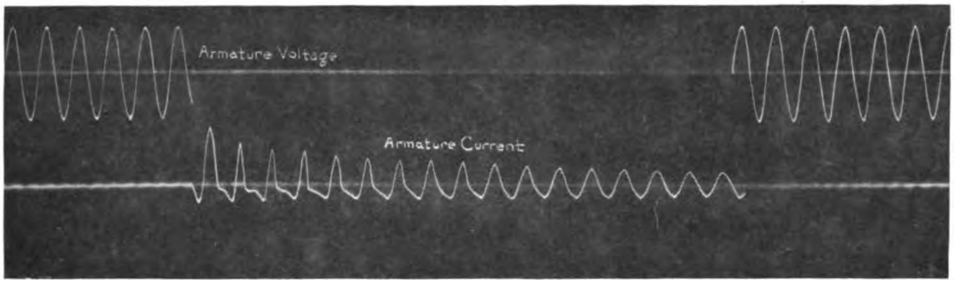


Fig. 3

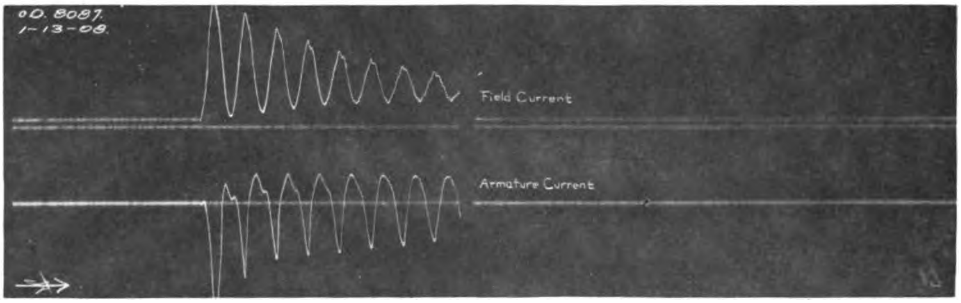


Fig. 4

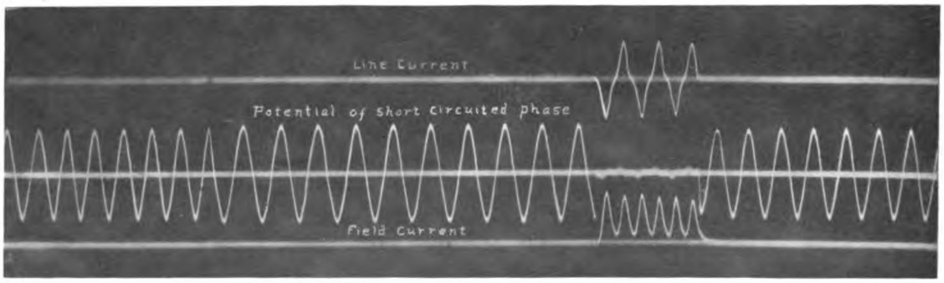


Fig. 5

The impedance of the circuit is,

$$Z=\sqrt{0.10^2+0.01^2},$$

or very nearly 0.10; therefore the current $=\frac{1}{0.10}=10$ (full load being 1), and the torque at the first instant of short circuit is $10\times0.09=0.9$, or only 90 per cent. of the full load value.

The impedance $Z=\sqrt{0.01^2+0.025^2}=0.027$; the current $=\frac{1}{0.027}=37$ (full load being 1), and the torque $37\times0.37=13.7$, or 13.7 times the normal torque.

The *armature reaction*, although of no importance at the first instant of short circuit, eventually largely determines the final current, which is usually from 2.5 to 3 times the full load value, in engine driven as well as turbo-generators. The field flux at that time is very small—about 1 per cent. of the normal—and therefore the torque is very small and can be neglected.

The effect of the armature reaction, or the magnetization or demagnetization by the armature current, cannot take place instantaneously. In the case of a short circuit where there is only reactance and resistance the current becomes lagging and the effect of the armature current is to demagnetize the poles.

The rate at which the field flux disappears depends upon the time constant of the circuit; that is, of the eddy circuits as well as the main field circuit. The time is shorter if the field structure is laminated and the exciting circuit has high resistance, than if the field poles are made of steel and the winding of low resistance—assuming the same exciting voltage in each case.

The time of dying away of the current thus varies in different machines and may be from a fraction of a second to a couple of seconds.

In this connection it is of interest to note that not only is the armature current excessive, but a very large current flows in the field winding at the time of a short circuit. This field current may well be so large as to trip a circuit breaker in the field circuit, in which case the field winding is subjected to a very high voltage.

The field winding is really the secondary of a transformer, having the armature winding as primary and the iron circuit of the armature and field structure as core.

To illustrate this, in Figs. 3 and 4 are shown oscillographs of the line voltage, and armature and field currents, at the time of short circuiting the three phases of a 5000 kw. turbo-generator, at approximately one-quarter voltage. It is interesting to note that in this case the frequency of the field and armature current is the same. This is, however, not always so, as is shown in Fig. 5, where the voltage, and armature and field currents of a definite pole water turbine driven generator are given. In this case the short circuit was made on one phase only. It is seen that the frequency of the induced field current is double that of the armature current. Here, the frequency depends upon the particular part of the electromotive force wave where the short circuit occurs.

To overcome the effects of the enormous stresses which occur during the first few fractions of a second of a short circuit, it would seem necessary only to demand generators with high resistance or self induction.

Theoretically, this would be the solution, but practically, there are extremely great difficulties to be overcome in making a winding which will have a considerable self induction, and not increase, at the same time, the armature reaction, which latter must be kept low in order to get a fair voltage regulation under load.

An ordinary turbo-generator has a regulation of 8 per cent. with non-inductive load, and a final short circuiting current, governed by the armature impedance and armature reaction, of about 2.5 times full load value. If by re-design we were able to get 40 per cent. more turns on the armature, the impedance would be doubled and the armature reaction increased 40 per cent.

The instantaneous short circuiting current would then be only 20 times the normal instead of 37 times as in the first case, and the torque only about 4 times normal instead of 13.7 times; but the voltage regulation would be prohibitively poor—from 15 to 18 per cent.

By the use of *external reactances* in connection with turbo-generators as built at present, the difficulties due to short circuits can be greatly reduced without appreciably affecting the regulation, since the regulation depends upon the "synchronous impedance," which is only slightly increased by the added reactance.

These reactances should be placed in the generator leads as near to the machine as possible so as to eliminate the likelihood of a short circuit taking place between them and the generator, or they may be placed at the junction of the three windings in Y connected generators. In the first case, in addition to serving as a protection against mechanical strains, they save the generator winding, to a certain extent, from high frequency surges from the outside; they also limit the current which would flow from other machines on the same bus bar in case of a short circuit in the generator winding. In the second case they do not offer these last two advantages, but they protect the generator from its own current if the short circuit takes place in the winding proper.

The first arrangement seems preferable in large systems where many generators are operated in parallel, the latter in stations of one or a few units only. With 25 cycle generators, at least, the installation of such reactances seems highly desirable, and although not so necessary, they may form a desirable protection with 60 cycle machines.

The amount of reactance for 25 cycle generators may be from 3 to 6 per cent.

To illustrate numerically the effect of the installation of 6 per cent. reactance in connection with the generator discussed above, the following deductions have been made:

Total reactance is $6\% + 2.5\% = 8.5\%$. The total resistance (neglecting resistance of the reactive coils, which would be a fraction of one per cent.) is 1%; thus the total impedance, $Z = \sqrt{0.01^2 + 0.085^2} = 0.085$, and the short circuiting current $= \frac{1}{0.085} = 11.7$.

The phase relations are given in Fig. 6, where $\tan \phi = 8.5$, $\phi = 83.2°$, and $\cos \phi = 0.13$.

The torque is therefore $11.7 \times 0.13 = 1.5$, or 50% more than that at full load. The regulation would be from 9 to 10 per cent. instead of 8 per cent. Incidentally, this emphasizes the undesirability of requiring close voltage regulation of turbo-generators.

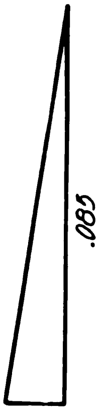


Fig. 6

The reactance, or reactive coils referred to, can readily be built in place in the station, or they can, of course, be manufactured by some electrical concern. If done by the station engineer, it has been suggested to build three cement cores at the foundation of the turbines and around these cores to wind properly insulated conductors, which, of course, need to have such cross section as to be able to carry the full load current of the generator, and such insulation as to withstand at least double full voltage against ground. The coils may be clamped down by a board, bolted to the cement cores.

Approximate Size of Coils for Three-Phase Generators

It will be assumed that the axial height is somewhat greater than the mean diameter of the coil; we have then:

$$T = 10\,E\sqrt{\frac{p}{d\,f\,\text{kw.}}}$$

$$AT = 5800\sqrt{\frac{p\,\text{kw.}}{d\,f}}$$

$$W = 5.8\sqrt{\frac{p\,d\,\text{kw.}}{f}}$$

Where

T = turns per coil
E = line voltage
p = per cent. reactance ($p = 3$ for 3%)
d = mean diameter of coil
f = frequency
kw. = kilowatt rating of generator
W = weight of copper per coil at 1000 amp. per sq in.

Example:

12000 kw. generator
9000 volts
25 cycles
3 per cent. reactance
Mean diameter, 30 in.

We then have:

$$T = 10 \times 9000\sqrt{\frac{3}{30 \times 25 \times 12000}} = 52$$

$$AT = 5800\sqrt{\frac{3 \times 12000}{30 \times 25}} = 40200$$

$$W = 5.8\sqrt{\frac{3 \times 30 \times 12000}{25}} = 1200 \text{ lbs.}$$

To go into the details of mechanical arrangement of these coils is outside the scope of this paper, and I shall only add that the relative positions of the cores are rather immaterial, so long as they are not placed on top of each other. With a reasonable mechanical clearance between the cores, or with considerable distance between them the reactance is substantially the same.

The coils may be cooled most conveniently by natural draught, in which case it is not desirable to use a higher current density than 1000 amps. per sq. in.; this will probably give about 0.3 watts per sq. in. radiating surface.

THE UNITED BOXBOARD AND PAPER COMPANY, LOCKPORT, N. Y.

By John Liston

This company affords a good illustration of modern methods in paper production, as it manufactures pulp by both the ground wood and sulphite processes, and operates two mills which utilize the product of the pulp mills. All the mills operate 24 hours per day except on Sunday, when the machinery is overhauled and cleaned. The daily capacity of the pulp mills totals 75 tons, and that of the paper mills, 110,000 pounds.

The ground wood mills are operated entirely by waterpower, and will not be further considered at this time. The sulphite and paper mills are electrically operated, and the accompanying wiring diagram (Fig. 2) shows how thoroughly the electrification of these plants has been carried out, and indicates the flexibility of motor drive as compared with mechanical drive for work of this kind.

Power is procured from the Lockport Electric Light Heat & Power Company; it is transmitted from Niagara at 12,500 volts, three-phase, 25 cycles, and stepped down to 440 volts in a small transformer house opposite mill No. 2. The General Electric Type I, Form K induction motor is used throughout the plant, with the exception of two A.C.-D.C. motor generator sets, also of General Electric manufacture.

It is interesting to note the saving in power obtained by the adoption of motor drive in this mill. The change from mechanical to electric drive was made about one year ago, prior to which time steam engines were used, with the customary shafts and belts. The mechanical drive required a capacity of 2250 h.p. and careful tests showed that 528 h.p. was consumed in friction losses on shafting. At present, with a total capacity of 1700 h.p. in motors, the production is greater than it was with the old steam plant of 2250 h.p.

In addition to this, the amount of belting required has been reduced by 50 per cent., in spite of the fact that most of the motors are arranged for belt operation.

This installation exemplifies the reliability of modern electric motors under severe service conditions, as the mills operate 24 hours per day, six days in the week, and during the year that the motors have been installed, they have been subjected to this practically continuous operation without having involved a single break-down or any cost whatever for repairs.

The motors are not housed in in any case, but are cleaned each week with compressed air, at which time the lubrication is renewed.

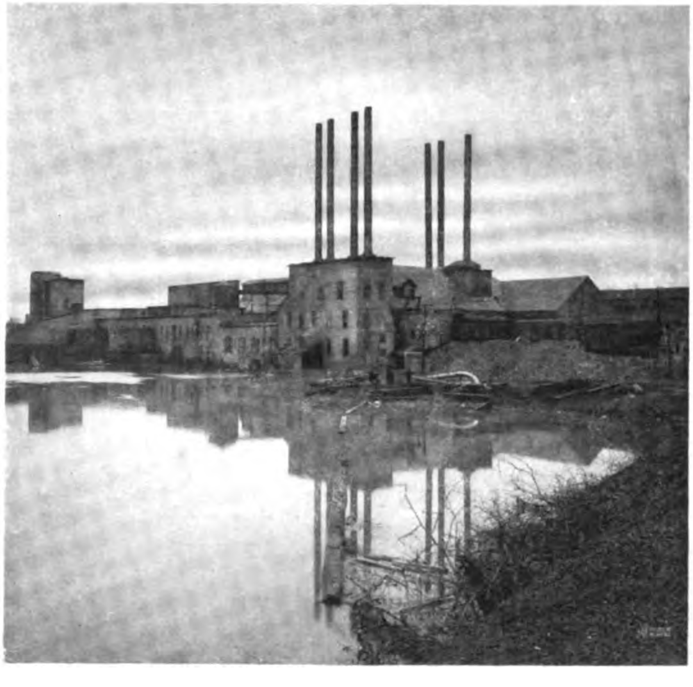


Fig. 1. General View of Sulphite and Paper Mills The United Boxboard and Paper Co., Lockport, N. Y.

Those operating the beating engines, screen pumps and wet machines are protected somewhat by being installed on the floor below the machines, driving by means of belts.

The six motors on the two sets of Jordans are direct connected and operate without any protection from flying dust or dirt (see Fig. 3). These motors are constructed

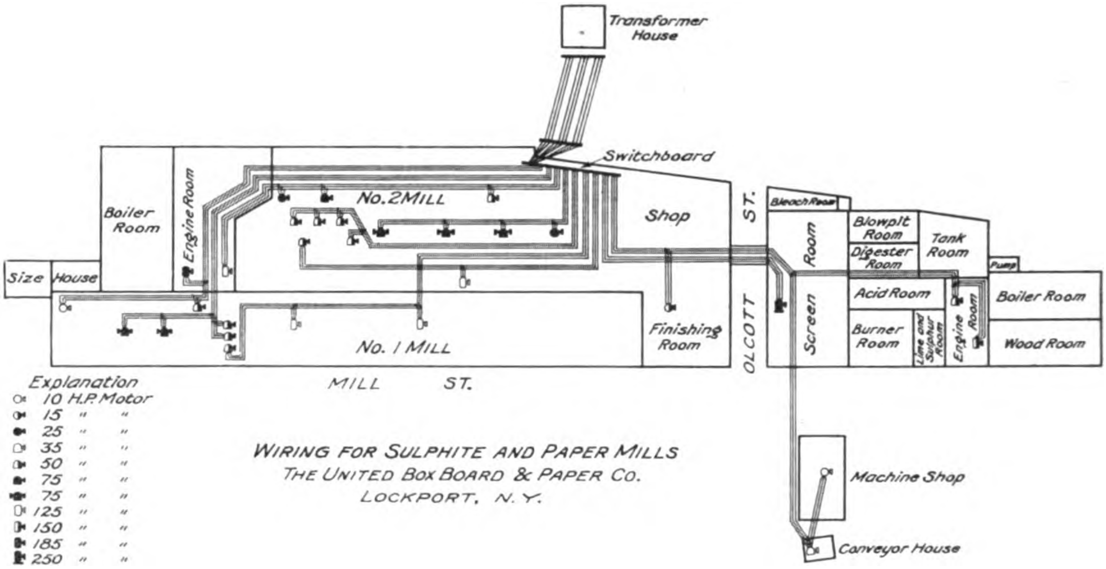

Transformer House
Switchboard
Boiler Room
Engine Room
No. 2 Mill
Shop
Bleach Room
Blowpit Room
Digester Room
Tank Room
Pump
Acid Room
Boiler Room
Screen Room
Burner Room
Lime and Sulphur Room
Engine Room
Wood Room
Size House
No. 1 Mill
Finishing Room
Olcott St.
Mill St.
Machine Shop
Conveyor House
Explanation
10 H.P. Motor
15 " "
25 " "
35 " "
50 " "
75 " "
75 " "
125 " "
150 " "
185 " "
250 " "
WIRING FOR SULPHITE AND PAPER MILLS
THE UNITED BOX BOARD & PAPER CO.
LOCKPORT, N. Y.

Fig. 2

so that the shaft has an end play of 2½ inches on either side of the center; this arrangement insures the simplest possible adjustment of the Jordans and while no trouble has been experienced in operation, its theoretical disadvantages have been overcome by the design illustrated in Fig. 4, which shows a G.E. Form L Motor arranged to slide on its base when actuated by a threaded shaft geared to the Jordan adjusting handwheel. With this arrangement of motor drive the rotor need not be displaced, and the maximum efficiency of the motor is maintained, irrespective of the adjustment of the Jordan.

The general adaptability of motor drive to plants originally designed for steam engine drive is evidenced by the fact that practically no reconstruction of buildings was entailed, nor special foundations required in the case of the Lockport plant, in spite of the age of the buildings, which, for the Sulphite Mill, was 7 years, for Paper Mill No. 2, 8 years, and for Paper Mill No. 1, 14 years.

In addition to the induction motors specified opposite, there are two 125 h.p. direct current motors, each operating the variable speed end of one of the paper machines. Direct current at 500 volts is provided for these motors by two motor generator sets, each consisting of a 4-pole, 150 h.p., 750 r.p.m., Form K, induction motor, direct connected to a CL-B 6-pole, 102 kw., direct current generator. This combination operates with the Ward Leonard system of control, which permits of any speed variation required in paper manufacture.

The details of the motor distribution are as follows:

Motor Distribution	No. Motors	H.P.	R.P.M.
Wood Room: Saws, Barkers, Splitters, Chippers and Rotary Screens	1	150	500
Acid Room	1	80	500
Screen and Wet Machine Room	1	250	500
Wood Conveyor	1	35	750
Machine Shop	1	10	750
PAPER MILL NO. 1			
4 Beaters	2	75	500
*3 Jordans	3	50	375
4 Screens and Pumps	1	185	500
3 Jordan Stuff Chests	1	50	750
Broke Conveyor	1	10	750
Suction Pumps, Felt Washer, and Constant Speed End of Paper Machine	1	125	500
PAPER MILL NO. 2			
6 Beaters	3	75	500
6 Stuff Chests and Water Softening System	1	50	750
3 Jordans	3	50	375
3 Stuff Chests	1	50	750
Centrifugal Water Supply Pump to Roof	1	75	750
Centrifugal Pump to Filters	1	50	750
Centrifugal White Water Pump to Beaters	1	25	750
5 Screens, Save-all Machines and Constant Speed End of Paper Machine	1	125	500
Carpenter Shop: 2 Elevators, Broke Conveyor and Water Pump and Filter	1	25	750
Roll Grinder and Elevator	1	15	750

* Motors direct connected

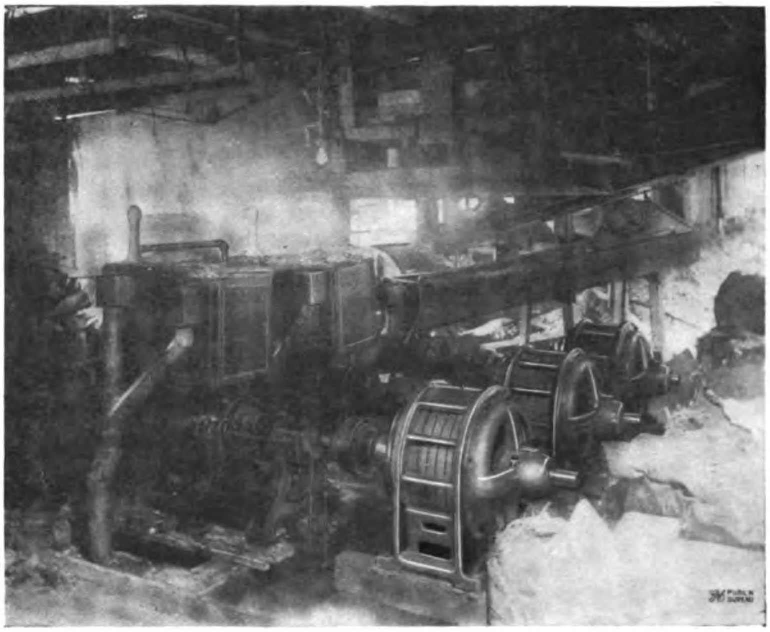


Fig. 3. 50 H.P. General Electric Form K Induction Motors Direct Connected to 3 Jordan Engines Note the Working Conditions under which these Motors Operate

In case of interruption to the service, a steam driven direct current generator of 25 kw. capacity is held as an emergency lighting equipment. The lighting is done by means of incandescent lamps, of which there are 1500 distributed in the various buildings. These are fed from two special transformers, of 150 kw. and 125 kw. capacity, through which the current is transformed from 440 to 110 volts.

The switchboard consists of one main and nine feeder panels, supplied with necessary knife switches and protected by circuit breakers and fuses. The main panel is provided with Thomson indicating ammeter and voltmeter, while the feeder panels are each equipped with a Thomson indicating wattmeter. As a further check on the amount of current consumed, a General Electric curve drawing wattmeter is connected to the busbars on the main panel; and as the Lockport Company pays for its current on the basis of maximum demand, this main panel is also provided with an overload relay which automatically connects a bell in the circuit, if at any time the predetermined peak load is exceeded.

The entire installation is one that illustrates graphically the inherent economy, reliability, and general efficiency of motor drive, and as such is worthy of the careful consideration of every practical pulp and paper mill owner and operator.

To those not familiar with the sulphite process of paper making, the accompanying diagram (Fig. 10) and typical illustrations together with a brief outline of the operations witnessed by the writer at the Lockport plant, may be of interest.

In many cases the logs are brought directly to the mill by water; at Lockport, however, they are received by rail, and the yard is equipped

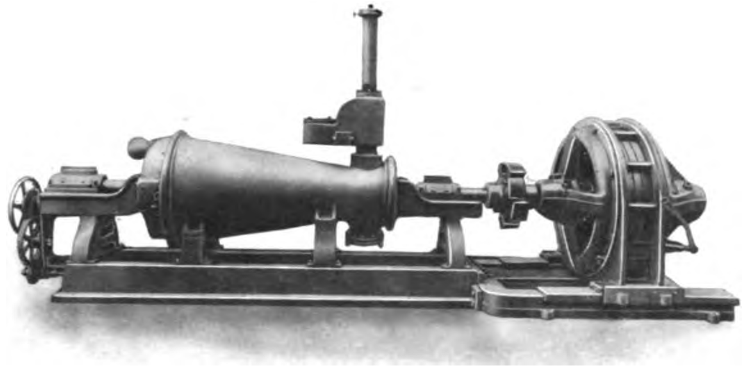


Fig. 4. General Electric Form L Induction Motor with Sliding Base, Direct Connected to Jordan Engine

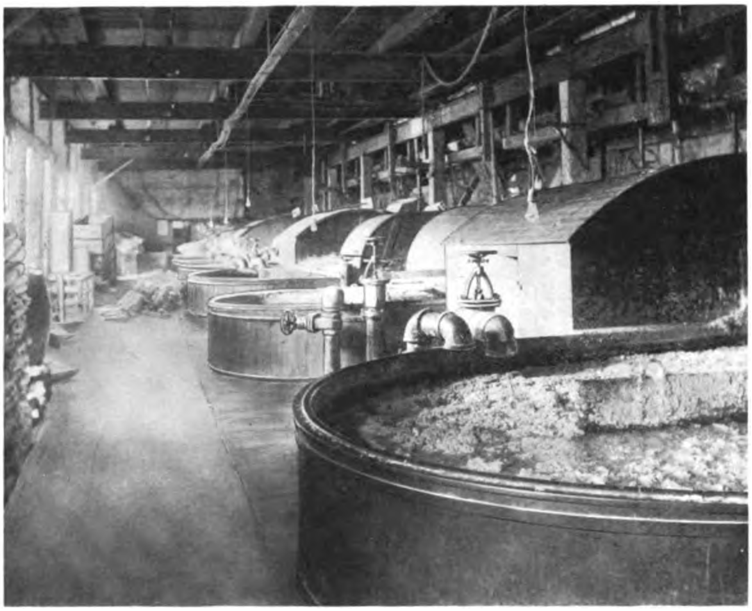


Fig. 5. Motor-Driven Beaters of 1100 lbs. Capacity each

for the operation of electric locomotives. The logs arrive sawed in lengths of four feet, and with the bark removed. They are carried from the storage yard by means of a wood or log conveyor and delivered to the wood room of the sulphite mill. Here they are sawed into two-foot lengths, and any bark that remains on them is removed by the barkers which consist of heavy knife blades mounted radially on a rapidly revolving metal disk.

Any logs that are too large for convenient handling are halved or quartered by the splitters which operate in the manner of an ordinary punch press, except that, instead of being fitted with dies, they are provided with heavy chisel-shaped knives. The logs, or bolts as they are called, are then fed to the chippers at an angle of 45 degrees. These chippers reduce the bolts to chips about the size of the thumbnail. The chips are then passed on by conveyors to rotary screens, where the knots, large chips and slivers are sifted out and discarded.

This rejected material is automatically conveyed to the wood burning boilers, while the chips suitable for pulp are transferred by conveyors to a chip loft on the fourth floor, having a storage capacity of thirty tons. Here, the chips are deposited in hopper-like bins, the outlets of which are located directly above the digester inlets.

The digesters at Lockport consist of two cylinders of 1¼ in. steel, each 11 ft. in diameter by 37 ft. high, lined first with 4 inches of concrete, and again with acid-proof brick pointed with litharge. Fig. 9 shows a group of typical digesters in course of construction.

On the floor below the chip loft is located the charging room, where the digesters are filled by simply removing the heavy iron cap and allowing the chips to enter the digester by gravity from the hopper-like chip bins. Each of these digesters can be loaded with its total capacity of 5 tons in about 18 minutes. The steam control valves for the digesters are also located on the charging floor.

The digesting process, which takes from ten to eleven hours, consists of saturating the

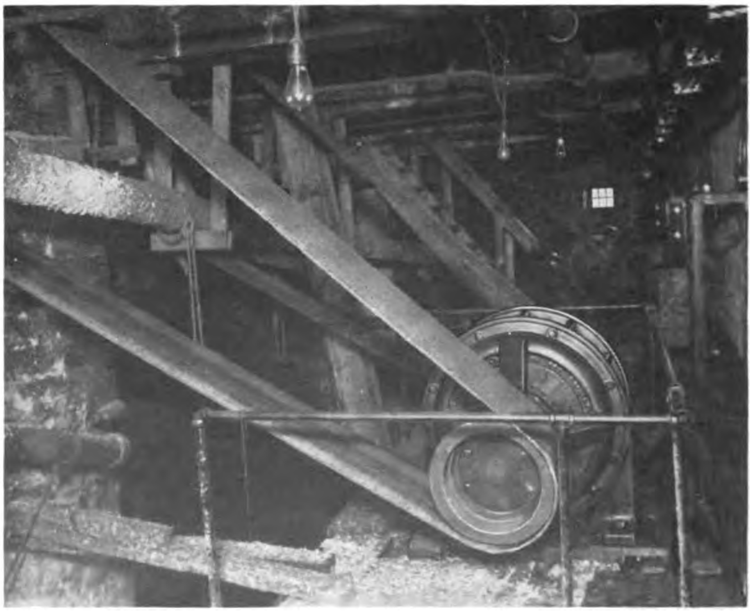


Fig. 6. Three 75 H.P. General Electric Double-Pulley Form K Induction Motors Driving 3 Pairs of Beating Engines

chips with sodium sulphite (which is manufactured on the premises by passing sulphur dioxide through milk of lime), and subjecting the mixture to the action of live steam; this results in reducing the chips to a pulp. The steam is then shut off and the pulp drawn off into blow-pits, where the liquor is allowed to drain off. The pulp is then washed with filtered water and pumped to the screen room, where it is washed through horizontal fine meshed screens (see Fig. 11) by heavy jets of water, those particles which are too coarse for use being automatically sifted out and drained off into a sewer. The pulp is now a thin milk-like liquid and is carried directly to the wet machines, where it passes over rolls which drain off the water and transform the pulp into wide thin sheets. When the operation is finished, a number of these thin sheets have been superimposed one upon another and converted into a thick sheet of what is known as "stock", and closely resembles heavy, moist white felt.

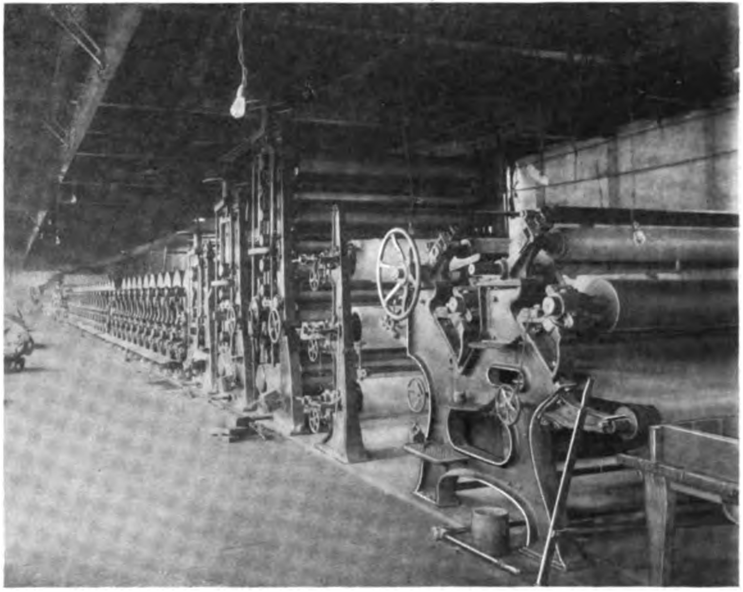


Fig. 8. Paper Machine in Mill No. 1, viewed from finishing end. The variable speed end of this machine is driven by a 125 H.P., D.C. Variable Speed Motor, the current for which is supplied by an A.C.-D.C. Motor Generator Set

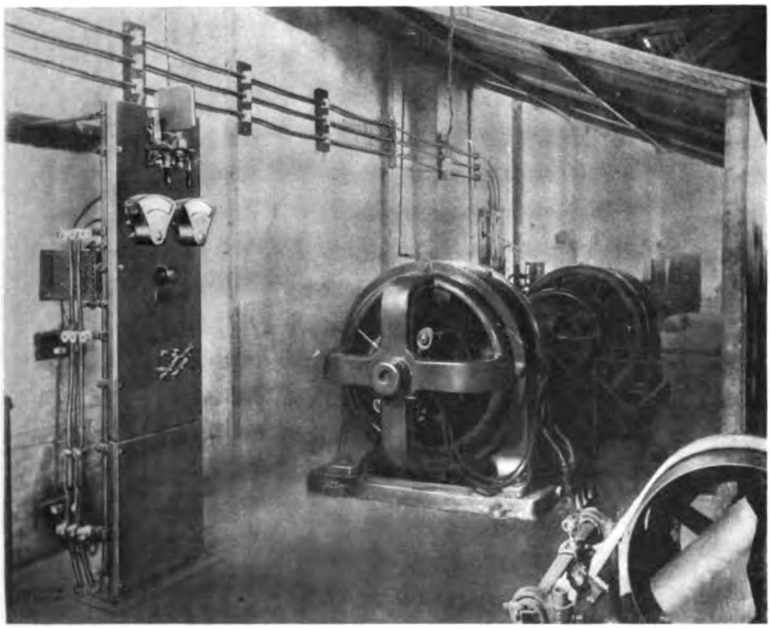


Fig. 7. Motor Generator Set for Operating Variable Speed End of Paper Machine

The "stock" is either stored for future use or passed on immediately to the beating engines (Fig. 5), which consist of elliptical tanks in which the stock is beaten into a fluid condition and mixed with clay, resin, and the necessary coloring materials for the finished paper. The beaters are usually driven in pairs, and at the Lockport plant are operated by double pulley General Electric motors mounted on the floor below. From the beaters, the material, which is now called "stuff", is conveyed to stuff chests, and from there passes through Jordon refining engines (Fig. 3) which still further reduce the size of the atoms held in suspension by the liquid.

After passing through a final screening process, the pulp is fed to the wet end of the paper machine; this consists of a wide band of fine meshed wire which runs horizontally over a number of rolls, and which allows the water to flow through. The residue is carried along on broad strips of felt, which in this case are each 144 ft. long. From the felt it is taken up in a thin sheet by revolving cylinders and automatically transferred to the drying rolls. At the Lockport plant, these latter consist of 59 hollow metal cylinders heated by steam and provided with siphons for carrying off the condensed water.

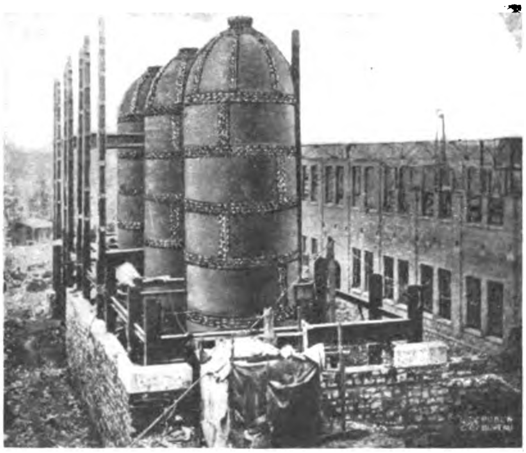


Fig. 9. Group of Three Typical Digesters

The paper now appears as a broad, continuous sheet, with a rather rough surface, and to give it the necessary finish it is passed through three stacks of calendar rolls, at the end of which operation it appears as a finished product, and is either cut up in sheets or wound in rolls for shipment.

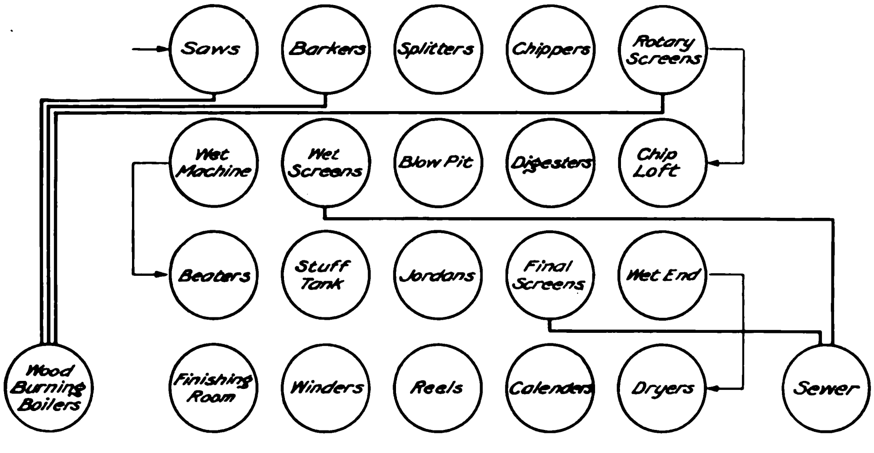


Fig. 10. Sequence of Operations in the Sulphite Process of Paper Making

While on the subject of paper manufacture, it might be well to consider briefly the problems involved in the operation of pulp and paper mills, and to analyze the inherent advantages of electric power for this particular class of work.

The practical paper mill operator will consider the application of electric power only when he can clearly see that it will insure, first, uninterrupted operation, and second, a saving in the cost of production either through a low installation expense or by increasing the quantity of the product for a given investment, or by a reduction in operating expenses. That electric power combines both of these features is evident from the following outline of the principal advantages it possesses when compared with mechanical drive.

1. The location of the power plant, whether steam or water driven, may be so selected as to obtain the greatest economy in the production of power, without regard to the arrangement or location of the manufacturing buildings.

2. The manufacturing buildings may be so arranged and designed as to eliminate all unnecessary handling of product, and since the heavy construction which is required where long shafts and heavy hangers are used is not necessary, a low first cost in foundations and building construction is secured.

3. The generating plant may be subdivided into two or more units, thus insuring against a complete shut-down in case of accident and permitting of economical operation at partial loads. In addition to this, a number of small water powers which might not otherwise be made available, can be utilized for the generating of electric current, and the total

result applied with a practically negligible loss in transmission.

4. The power may be subdivided so that individual sections of a plant driven by isolated motors can be started or stopped without interfering with the work of other sections that are in operation.

5. Great economy of power can be obtained by the use of direct drive, since the amount of shafting, belts, gears, idlers and other consumers of energy can be greatly reduced.

6. The power used by individual motors can be readily measured, and the indicating instruments will show at a glance whether the power consumed is normal or not. In this way, any defect in the machines which entails an unusual consumption of power can be readily detected and corrected.

7. As the power can be conveniently measured, all of the machinery may be operated at such speeds as will produce the best results with the least consumption of power.

8. Electric drive has great flexibility and permits the extending or enlarging of a plant without disturbing the existing conditions, and insures the economical application of power at any particular point in the plant. Any desired additions to the existing plant can be made without suspending operations.

9. The recent developments in the flaming arc, luminous arc, and tungsten incandescent lamps insure the maximum obtainable efficiency for night operation; these lamps can be run on the power generator circuits.

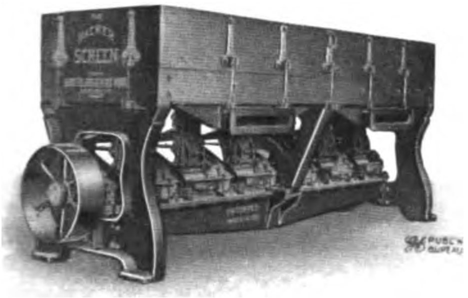


Fig. 11. Pulp Screen

10. In supplementing water-power with steam-power, the engine and generator may, of necessity, be located at a distance from the water power, and without other connections than the wires between the generators, may be arranged to automatically supply any deficiency in the power from the water-driven plants.

While the average pulp mill is operated by water power, the fact that the wood pulp can be stored for future use brings up the question as to whether or not motors can be profitably utilized for auxiliary power. If current can be obtained from an outside central station, motors can be installed and connected to the grinders. Many central stations, especially those that are dependent upon a variable water supply, will grant low rates for current during the flood seasons, and at other times low night rates can be obtained, as the utilization of power at night will enable the central station to bring up its load factor. By intelligently taking advantage of these conditions, which will vary somewhat in different localities, the average water-driven wood pulp mill can largely increase its productive efficiency with a minimum of additional investment.

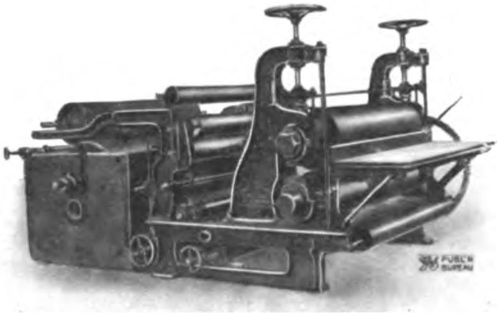


Fig. 12. Wet Machine

If a water-driven mill is located near other water powers that are not mechanically available, the fact that a water-wheel-driven generator can be installed and the power transmitted electrically with a practically negligible transmission loss, will render possible the utilization of any such additional power with a minimum of expense, and will frequently avoid the necessity of building other mills to increase production.

In cases where water-wheels are used to drive the auxiliary machinery, the use of water-driven generators will insure the application, through motors, of a greater percentage of the available water power than is possible where mechanical drive, with its heavy friction losses, is used.

TESTING OUTFITS FOR COLLEGE LABORATORIES

By E. P. Edwards.

Few of us possess more than a vague realization of the magnitude and importance of our educational system and its far reaching influence on the growth and progress of the country.

A better appreciation of the subject will be gained by a glance at the following table of statistics:

Universities, Colleges and Technical Schools in the United States

Number of Institutions	500
Value of Grounds and Buildings	$240,000,000
Income (1905–1906)	40,705,120
Value of Scientific Apparatus	28,000,000
Number of Students Enrolled	250,000
Number of Instructors	22,000

With these figures before us it does not require a vivid imagination to picture the mutual advantage to be gained by close cooperation between these institutions and the representative manufacturing concerns of the country. Only by such cooperation can the educational institution keep abreast of the times and advance the best interests of its students. From the manufacturer's standpoint this is a "consummation devoutly to be wished"; for his recruits must be drawn largely from the graduates of these institutions.

With this in mind, the General Electric Company has cultivated a close relationship with leading technical institutions, and each year takes into its Testing Department from 200 to 275 graduate students.

In normal years, the testing force consists of between 500 and 600 men, representing from 75 to 100 educational institutions. These men are trained to have an intimate familiarity with every class of electrical apparatus, and from their ranks the most capable are selected to fill positions in the engineering and commercial departments of the company.

This practice has met with such marked success that the Company has extended its policy in an endeavor to reach, indirectly, the whole student body. The means adopted for accomplishing this end may be enumerated as follows:

1st: Laboratory sets have been developed with particular reference to the varied requirements met with in the educational field. These sets embody in the one piece of apparatus the salient characteristics of several commercial machines. The low price at which they are offered places them within the reach of every technical school.

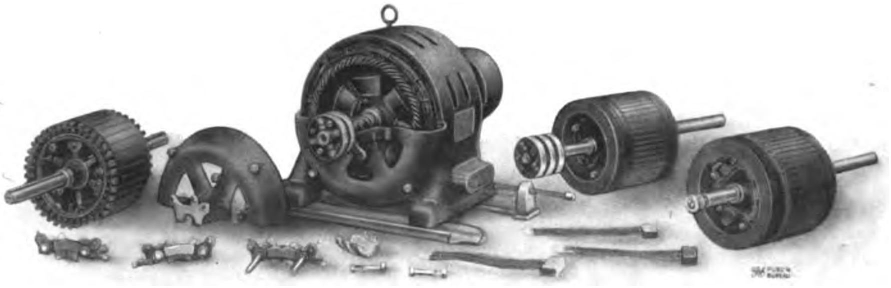


Fig. 1. Polyphase Generator A H B 6-7.5 Kw. 1200-220 Volts

2nd: Every consideration is given to requests for quotations on apparatus intended for use in the laboratory or for purposes of instruction, and in quoting prices on such apparatus the General Electric Company freely sacrifices material profit as its contribution to the cause of advanced science.

3rd: The Company and its personnel is always ready to assist with advice and such technical data as may be properly given out.

4th: The factory is always open for inspection, and graduating classes with their instructors are given every facility to thoroughly inspect the works.

5th: Display boards showing standard products of manufacture are available for exhibition purposes and will be supplied at consistently low prices. One such board is shown in Fig. 8.

A detailed description of the laboratory sets above referred to may be of interest and is appended.

POLYPHASE GENERATOR

This is a 6 pole, 7.5 kw., 1200 r.p.m., 220 volt, 60 cycle machine and is designed to operate either as a polyphase alternating current generator, a synchronous motor, an induction motor, or a frequency changer (Fig. 1). The following parts are supplied with the set to make possible its operation as any of the above named machines:

One stator, for use either as an armature of an alternating current generator or as an induction motor field.
One revolving field.
One squirrel cage, form "K," induction motor rotor, with starting compensator having self-contained switches.
One form "L" induction motor rotor with self-contained starting resistance.
One form "M" induction motor rotor with three-phase collector rings, external resistance, and controller.

Special Features of Adaptability

The stationary armature is provided with a twelve-terminal connection board to which each section of the armature winding is brought out. This will permit of the following combinations when the machine is operating as an alternating current generator:

7.5 kw.,	12-phase	diametrical	110 volts.
7.5 kw.,	6- "	"	220 "
7.5 kw.,	3- "	"Y"	380 "
7.5 kw.,	3- "	delta,	220 "
7.5 kw.,	2- "		310 "
5.0 kw.,	Single-phase	delta or "Y,"	380 volts, 220 or 310 volts.

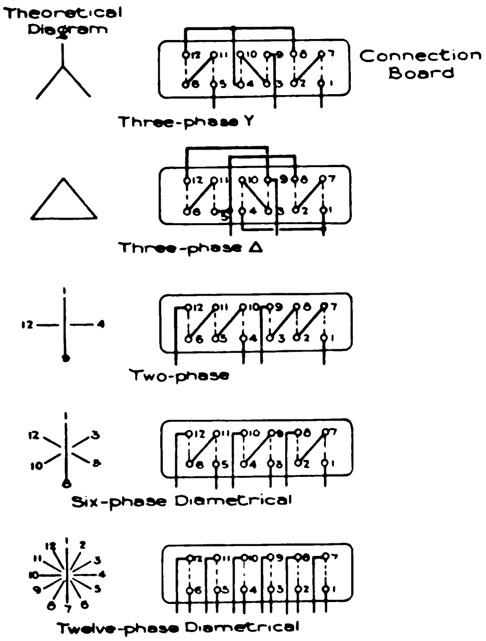
Fig. 2 indicates how these voltage combinations may be obtained from the connection board.

When these voltages are impressed on the armature from an outside source, the machine may be operated as a synchronous motor.

The three types of induction motor rotors represent different commercial forms and can be used to investigate the characteristics of the following machines.

7.5 h.p.,	3-phase	"Y,"	220 volts.	
7.5 h.p.,	3- "	delta,	127 "	
7.5 h.p.,	2- "		190 "	
7.5 h.p.,	6- "	diametrical,	127 "	per phase
5.0 h.p.,	single-phase	"Y,"	285 "	
5.0 h.p.,	" "	delta,	165 "	

When run with the form "K" rotor, the machine typifies the motor which is ordinarily used when a large starting current is not especially objectionable. By means of a starting compensator the initial rush of current is cut down to reasonable magnitude. The compensator connections for a three-phase motor are shown in Fig. 3.



Terminal numbers are stamped on the studs
Dotted lines represent winding coils

Fig. 2. Diagram of 12-Terminal Connection Board, showing Various Voltage Combinations

In using the form "L" rotor set a self-contained starting resistance is gradually cut out of the rotor circuit, as the machine comes up to speed, by means of a small handle at the end of the shaft.

With the form "M" rotor the use of the three-phase controller and external resistance allows resistance to be cut into or out of the armature—thereby decreasing or increasing the slip—and permits operation as a variable speed motor. The connections and development of a controller for use with this rotor are shown in Fig. 4, and an outline view with approximate dimensions is given in Fig. 5.

This set is also capable of operating as a frequency changer when using the form "M" rotor, the frequency depending upon the speed and the direction of rotation. If the form "M" rotor is driven at normal speed in the opposite direction to that in which it would revolve as a motor, a frequency of 120 cycles and a voltage between collector rings of approximately 145 volts may be obtained, when normal three-phase voltage at 60 cycles is impressed on the stationary armature.

Construction of Machine

Much thought has been spent in deciding upon a convenient arrangement for this machine. It possesses a wide range of voltage and outputs ordinarily not obtainable except with several different units. It occupies the least possible space, and its weight is such that the revolving parts can be shifted by hand. The conductors on the stator and on the induction motor rotors are embedded in slots, the coils being form-wound, separately insulated and tested, and interchangeable. The revolving field is equipped with short circuiting collars under the pole tips, to insure successful operation as a synchronous motor. The stator and rotors are built up of laminated steel. The bearings are contained in end shields, are self aligning, and are lubricated by means of oil rings. One of the end shields is so designed that the revolving field and form "M" rotor can be removed without taking off the collector rings.

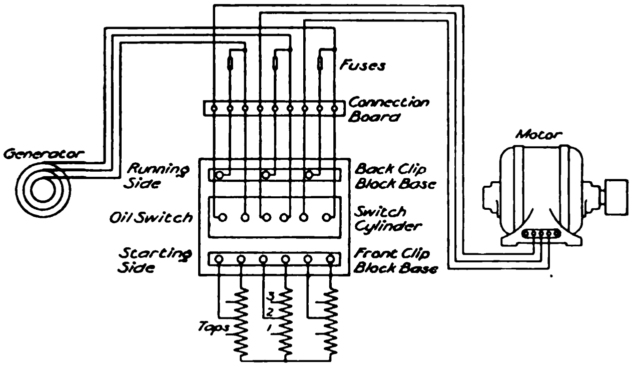


Fig. 3. Compensator Connections for Three-Phase Motor

The spring plug terminals for changing the terminal connections constitute another practical feature, and render it possible to make rapid and positive connections without the use of a wrench or screw driver. The electrical design is such that the e.m.f. wave of the generator is practically a sine wave. The field excitation is approximately 1 kw., at 125 volts.

Floor Space and Weights

The approximate floor space of this set over all, including wooden base, is 42 in. by 19 in. The approximate net weights are as follows:

Stator	450 lbs.
Revolving field	255 "
Form "K" rotor	160 "
Form "L" rotor	200 "
Form "M" rotor	200 "
Pulley and rails	70 "

DOUBLE CURRENT GENERATOR SET

This is a shunt wound machine and is rated, in the nomenclature of the General Electric Company, ACS 4-pole, 10 kw., 1800 r.p.m., 110 volts. The rotating element consists essentially of a direct current armature, with leads connected to slip rings located at the opposite end of the armature from the commutator. It is furnished, when desired, with speed-limiting and end-play devices, and with rheostats for field control and for starting from the D.C. end.

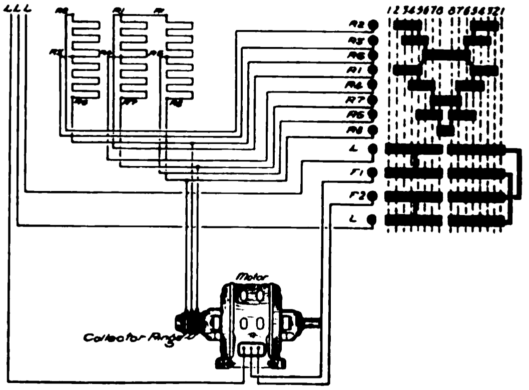


Fig. 4. Connections and Development of Controller for Use with Form M Induction Motor

Construction of Machine

The machine has the usual desirable features of General Electric apparatus, being representative of their standard rotary converter construction. The armature conductors are embedded in slots. the coils being machine made, separately insulated and tested, and interchangeable. The commutator and brushes operate well under all conditions of load, and ample ventilation of the rotating part is insured by the presence of ventilating ducts. The brushes are provided with flexible conductors for connection to brush holders and allow free movement of the brush in the holder, at the same time maintaining good contact. The pole pieces are of laminated steel and are separate from the magnet frame; they are furnished with copper bridges and collars to insure stable operation when the machine is run as a synchronous motor or rotary converter. The bearings are self-aligning and the frame is divided horizontally; the assembly of this machine is therefore a simple process. A driving pulley is mounted on an extended shaft as shown.

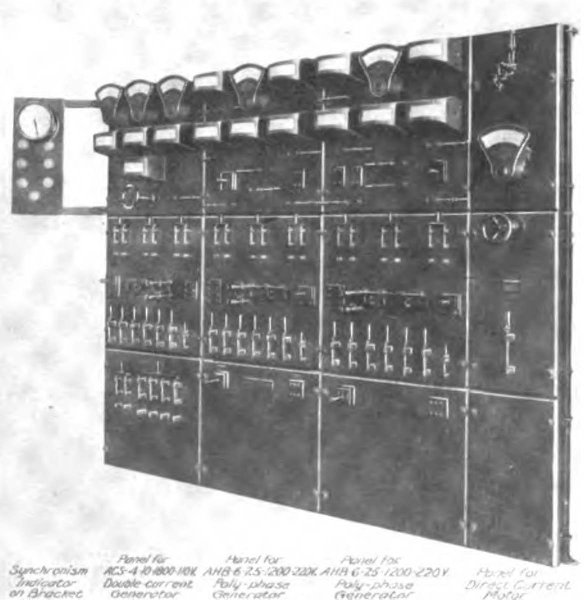

Synchronism Indicator on Bracket
Panel for ACS-4-10-1800-110V. Double-current Generator
Panel for AHB-6-25-1200-220V. Poly-phase Generator
Panel for AHB-6-25-1200-220V. Poly-phase Generator
Panel for Direct Current Motor

Fig. 6. Switchboard Panel for Double Current Generator.

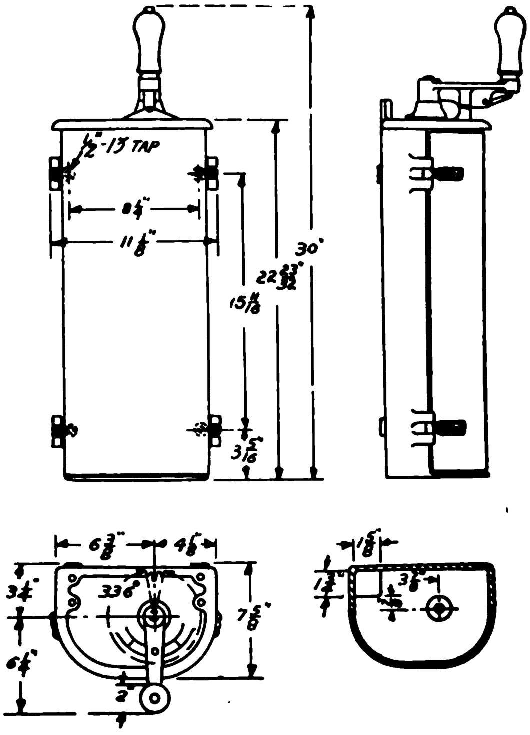

½"-13 TAP
8¼"
11⅛"
30"
22 23/32"
15 11/16
3 5/16
6⅜"
4⅝"
3¼"
336
7⅝"
6¼"
2"
1⅝
1¾"
3⅝

Fig. 5. Outline of Controller for Use with Form M Induction Motor

Special Features and Adaptability

The double current generator is provided with six collector rings, an arrangement that permits of single, two- and three-phase operation.

The generator can be operated as a 60-cycle machine with voltage variation of from 110 to 160 volts on the D.C. side, under any of the following conditions:

(1) *As a Rotary Converter.*

Machine will give approximately the following voltages.

Direct current, 110 to 160 volts.

Three-phase, 70 to 102 volts, with leads taken from rings 1, 3 and 5.

Two-phase, 81 to 115 volts, with leads taken from rings 1 and 4, 2 and 6.

The above voltages are the minimum and the maximum, respectively, of the range for which the machine is designed. When run as a rotary converter there will be but slight change in voltage ratio (A.C. to D.C.) with change in the load.

(2) *As a Double Current Generator.*

The machine can be operated at all the voltages mentioned under heading (1) with the following additions:

Single-phase, 81 to 115 volts, with leads taken from 1 and 4 or 2 and 6.

Additional single-phase voltage of 70 to 102 may be obtained from rings 1 and 5, 3 and 5, or 1 and 3; these voltages being secured by varying the shunt field excitation with the field rheostat.

(3) *As a Direct Current Generator.*

The machine has a range of from 110 to 160 volts.

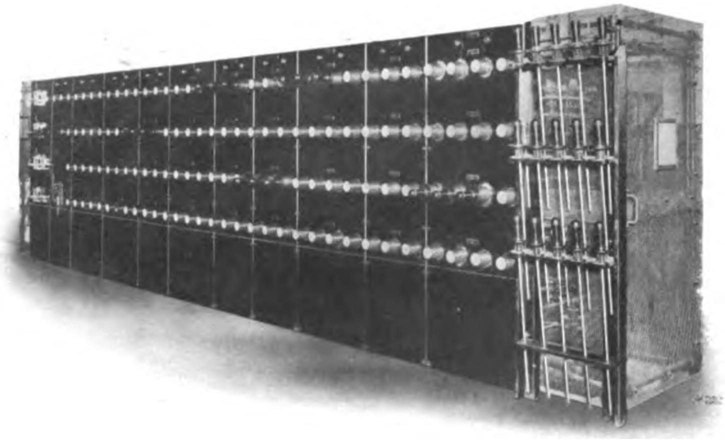


Fig. 7. Plug Switchboard in Use in Testing Department of General Electric Company

(4) *As an Alternating Current Generator.*

The machine is designed for operation at voltages mentioned under headings (1) and (2).

(5) *As a Direct Current Motor.*

The machine will operate on 110 to 160 volt circuits.

(6) *As a Synchronous Motor.*

The machine is designed for operation on circuits of approximately the voltages mentioned under heading (1).

(7) *As an Inverted Rotary Converter.*

The machine will operate with the same voltages as mentioned under headings (1) and (2).

With these voltages the machine is capable of successful operation as a rotary or as a generator, with an output of 10 kw., except when operated single-phase. When this is the case its capacity is 7.5 kw. When used as a synchronous motor its capacity is 10 h.p., and 7.5 h.p. when run from polyphase and single-phase mains respectively.

Floor Spaces and Net Weights

The approximate over-all dimensions are: Length along shaft, 4 ft., 5 in.; width, 4 ft., 6 in.; height, 3 ft.

The approximate net weights are as follows:

Armature and commutator . .	200 lbs.
Machine complete with pulley (without rails)	1500 "
Rails	70 "

This machine can also be furnished shunt wound for 230 volts, in which case it is rated ACS 4 pole, 10 kw., 1800 r.p.m., 230 volts. It is not designed for such wide range of voltage as the first machine, although it is capable of full kilowatt output at 220 volts. It may be operated in exactly the same manner as

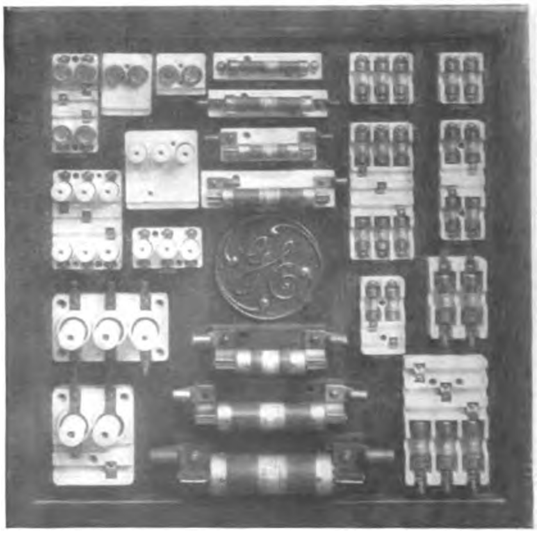


Fig. 8. Display Board of Standard Fuses

the 110/160 volt double current generator, but the A.C. voltages will be as follows:

Three-phase, 146 volts, with leads taken from rings 1, 3 and 5.

Two-phase, 167 volts, with leads taken from rings 1 and 4, and 2 and 6.

Single-phase, 167 volts, with leads taken from rings 1 and 4, or 2 and 6.

Additional single-phase currents of 146 volts may be obtained from rings 1 and 5, 3 and 5 or 1 and 3.

SWITCHBOARD

For the purpose of properly controlling the sets above described, switchboard panels have been designed (Fig. 6). The advantages of these switchboards cannot be over estimated; the student becomes acquainted with the methods employed in modern switchboard manufacture and operation, gaining at the same time an insight into the wiring and arrangement of meters, switches, etc.

Another method of control which, however, is not so well adapted to small installations, is that used by the General Electric Company in its Testing Department. This system involves the use of a plug connection board, shown in Fig. 7, and the testing tables, views of which are shown in Figs. 9 and 10.

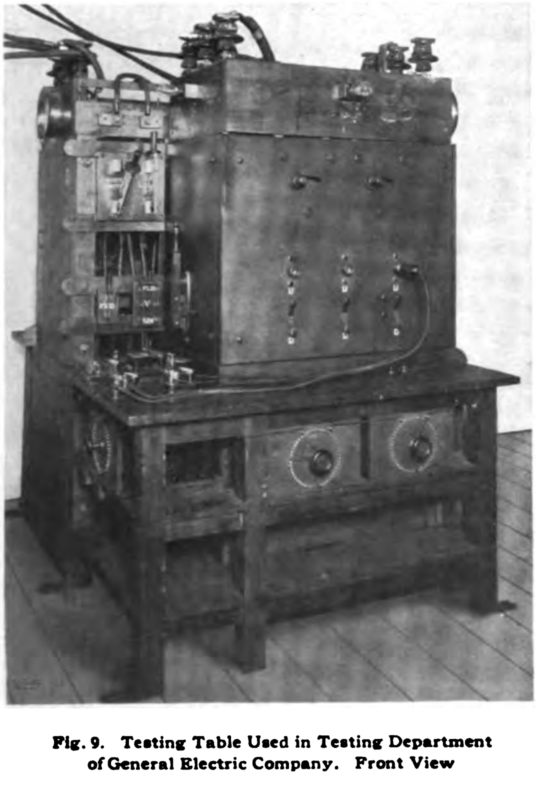


Fig. 9. Testing Table Used in Testing Department of General Electric Company. Front View

The machines to be tested are temporarily located at various points in the different buildings used for testing purposes, and in the immediate vicinity of a testing table. These testing tables are connected to the plug board by cables laid in ducts. The leads from the generators furnishing current for testing are also run in ducts to this plug board, and any testing table may be connected to any generator, irrespective of its location, by using the proper combination of plugs.

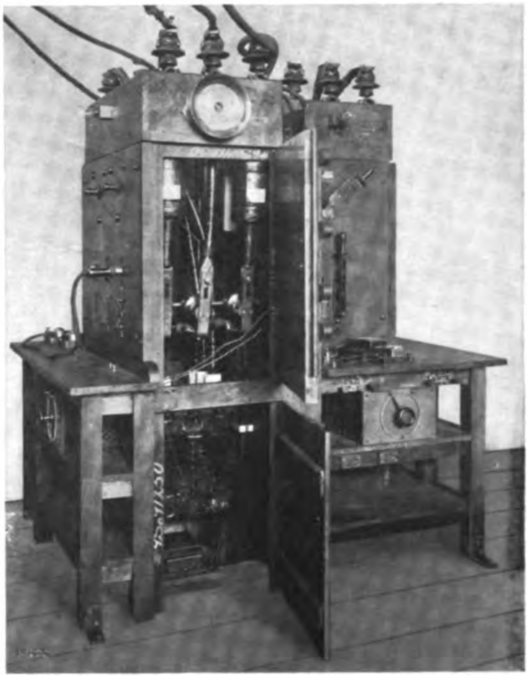


Fig. 10. Testing Table, Showing Interior

The plug board and the tables are constructed of slate, and enclose the oil switches, transformers, and such other apparatus as is subjected to high potential.

Portable instruments are used, and all cables are run under the floor. With this system, danger is reduced to a minimum and the greatest flexibility is secured.

A similar scheme may be used in the college laboratory, but it is usually found that the standard switchboard best meets laboratory requirements.

The General Electric Company can furnish either the switchboard, or portable instruments, switches, circuit-breakers and other controlling apparatus.

STREET LIGHTING FROM INTERURBAN RAILWAY CIRCUITS

By G. N. Chamberlin

The rapid growth of the interurban railway, aside from the additional transportation facilities offered, has made it possible for the smaller towns through which its lines pass, to avail themselves of the advantages to be derived from the use of electricity for lighting and power service.

In the early days of the introduction of the interurban railway, the transmission lines were restricted in length to a distance commensurate only with that over which a direct current of nominally 500 volts could be economically transmitted. Street lighting from its circuits was not considered, for the reason that the regulation for that class of service was poor. The development of street lighting units was restricted to one class only, operated from specially designed constant direct current generators.

With the development and introduction of the alternating current in connection with the interurban electric railway transmission, and the great improvements made in both arc and incandescent lighting units, it became a simple problem for small towns situated along the routes of such transmission lines to have their streets economically lighted by arc and incandescent units of the same efficient design as those used in the larger towns and cities, where current is furnished by companies formed exclusively for that purpose.

The high voltage transmission lines, made possible by the use of alternating current, invariably render available a large surplus of railway feeder capacity, a relatively large size of wire being necessary for mechanical strength.

With this high voltage and ample capacity, the variation is well within the allowable limits of both series and multiple transformation for lighting circuits.

The frequency at which railway current is generated, however, is much lower than that commonly employed primarily for lighting. Where the frequency of the current is not less than 25 cycles per second, its use for incandescent lighting is considered satisfactory. The electric arc, however, when operated at frequencies as low as 25 cycles, is not considered satisfactory for all classes of illumination.

The undesirable characteristics of the carbon arc when operated at low frequencies can be largely counteracted by the use of high current, opal inner globes, and by suspending the unit beyond the range of direct vision.

Heretofore, the operation of low frequency arc lamps has been questionable on account of the use of very light springs to deaden the vibration of the armature. There is now available a lamp built on an entirely new principle, eliminating all springs and thereby furnishing a more desirable mechanism for low frequency circuits than has heretofore been used on the higher frequencies commonly employed for constant potential arc lighting.

While the use of arc lamps connected directly to the lower frequencies employed with interurban construction may be considered questionable, as explained heretofore, the introduction of the series mercury rectifier with the D.C. luminous arc lamp has placed a system of street lighting at the disposal of towns in the vicinity of interurban lines, which is as modern as that available from stations designed primarily for lighting purposes. These recommendations must not be considered new, or of an experimental nature, as equipments of 12, 25, 50 and 100 lights capacity have long been considered standard. Many rectifier sets and thousands of lamps are being used by the larger low frequency generating stations throughout the country, the most prominent of which are Baltimore, Toledo, Syracuse, and Portland, Ore.

The station apparatus is simple, compact, without revolving parts, and consists of a constant current transformer, a direct current reactance, a mercury rectifier tube with tank, and a controlling switchboard panel. The transformer is of the well-known constant current floating oil type, which serves the double function of delivering the required voltage and maintaining the current at a constant predetermined value. Its construction is such as to admit of a variety of windings, meeting a wide range of voltage and frequency. Where the primary voltage is above the economical range of design, a constant potential transformer may be employed. The direct current reactance used in series with the rectified circuit is placed underneath and is part of the constant current transformer. Its purpose is to smooth out the pulsating current waves delivered to the circuit, thereby eliminating any unsteadiness at the arc which otherwise would be apparent.

The changing of this low frequency alternating current to an unidirectional current suitable for the operation of constant current series arc lamps of the luminous type, is accomplished by the use of a mercury rectifier tube. The tube consists of an exhausted glass vessel partially filled with mercury. Suitable terminals are brought out for the purpose of conveniently connecting it to the circuit.

In order to get the best results, it is necessary to keep the temperature of the tube within certain limits (approximately 50° C. to 90° C.). This was first accomplished by the blowing of air upon the condensing chamber of the tube; but the systems more recently installed have each tube immersed in a small tank filled with oil, the temperature of the oil being kept within the required limits by means of water circulation. This method of regulating temperature has been successfully and economically employed in connection with high capacity potential transformer design. Experience has also proved that less attention is required from the station operator when tubes are oil-cooled.

The switchboard panel is of blue Vermont marble, suitably supported on a pipe frame and generally placed in front of the constant current transformer which it controls. The devices mounted on the panel are those ordinarily used for controlling series circuits, the most important being high voltage primary plug switches and one secondary ammeter.

The illumination unit used in connection with the constant current transformer and rectifier just described, is the luminous arc lamp. This lamp is the outcome of years of scientific investigation, and represents the most efficient illuminant available for street lighting purposes.

At its annual convention held at Chicago, May, 1908, the National Electric Light Association accepted the report of its committee of representative illuminating and central station engineers, which placed the luminous arc in a class by itself, far ahead of all other illuminants investigated for street lighting purposes.

The high efficiency of the luminous arc is obtained through the use of electrodes composed of materials which, when vaporized, form a brilliant and highly efficient illumination. The luminous vapors in the arc are furnished by the negative electrode, which consists of an iron tube filled with a mixture of the necessary material. This electrode has a life of 175 to 200 hours. The positive or upper electrode is of copper, and is practically non-consuming. The long life which is obtained from both electrodes insures a low maintenance cost.

It is often found necessary, more especially in the smaller towns, to arrange the public lighting in accordance with the funds available. In some instances it becomes necessary to use units of a small illuminating value in the outlying districts, and for this class of service the tungsten lamp, adapted for use in series with the arc circuit, is available.

From the foregoing, it is evident that standard apparatus is available for the economical and efficient illumination of the smaller towns along the lines of the interurban railway. That the acquisition of this class of business is attractive to the railway company is evidenced by the natural characteristics of a lighting station's load curve. Ordinarily, the maximum evening load of a railway station commences at about 5:30 and lasts for about one to one and one-half hours. Although this peak is, for about four months of the year, overlapped by the lighting peak, this disadvantage is more than offset by the nature of the lighting load and the length of time it remains on the station after the railway peak has disappeared, thereby enabling the railway company to generate its current during the hours required for street lighting at a cost which will admit of profit to both the railway and distributing companies. The distributing company may be one organized by interests closely allied with the railway company, or by outside interests, solely for the purpose of buying, transforming, and distributing the railway current for lighting purposes. In either case the investment required would be the same, since the current furnished is delivered to the point of distribution. The question of providing a transforming station to house the required apparatus needs but little consideration, for the reason that the design of the transforming apparatus is simple, compact, and needs practically no operating attendance. It would therefore be entirely feasible to use the railway company's local ware-room, or part of some occupied store room for this purpose.

In considering the expense incidental to the installation of the necessary apparatus, take for example a town requiring twenty-five luminous arc lamps. The total investment necessary to purchase and install a series system of the above number of lamps, including lines and structures, would be approximately $3,000.00.

The transforming apparatus might be installed in the same local building occupied by the rest of the outfit, paying rent at the rate of about $12 a year, and securing the services of one of the male occupants to look after its operation. The nature of the apparatus and the hours during which it operates—dark until midnight—makes such an arrangement entirely practical. The services of such an attendant could doubtless be secured for about $15 per month, as the transforming apparatus would only require occasional watching, and would in no way interfere with the attendant's regular duties.

On account of the long life of the electrodes, trimming would be required once per month; this could be so arranged that only one lamp per day would need attention. The trimming could therefore be done by the attendant for an additional $1.25 per month.

In addition to the above items, annual operating expenses of $207 must be added, cost of electrodes for trimming, globe renewals, rectifier tube renewals, depreciation at 5 per cent., and the cost of current furnished by the railway company, which makes a total of $683.80 per year, or approximately $700.00.

The probable income from the town would be about $50 per lamp per year, or a total of about $1250. A profit of $550 per year would then be derived by the operating company, which would admit of a dividend of about 18 per cent. on the original investment.

The figures given apply to a system devoted exclusively to street lighting, a condition of affairs which would rarely exist, for the reason that apparatus and lines for transforming and distributing current for commercial purposes could be introduced and maintained at a comparatively low cost.

The same housing used for the street lighting apparatus could also be utilized for what little additional apparatus is required for a commercial lighting and power circuit. The poles and cross arms already installed could also be used to a great extent. The total cost of all additional apparatus required, including lines, transformers, meters, and extra poles, would not exceed $3,000. The attendant's wages would be increased about $5 per month, and the rent might amount to slightly more. The current purchased from the railway company for commercial purposes, on account of its being nearly all "peak current," would be at a higher rate than current furnished for street lighting (2½ cts.), and would probably amount to a total of about $550 per year. In estimating the amount of energy required per year, figures were based on a two hour daily consumption of energy for one 8 c.p. incandescent lamp per inhabitant (1000).

The total annual operating expenses, including depreciation, would therefore be about $800. The annual income, considering an average price of 7 cts. for all current sold by the distributing company, would be approximately $1500. The annual profits would be approximately $700.00, thus enabling the distributing company to earn a surplus of about 26 per cent. from the sale of commercial light and power. Considering the total amount invested for street and commercial lighting apparatus ($6000), a dividend of about 20 per cent. could be earned.

It seems evident that this class of desirable business should be considered by interurban railway managers, as well as by individuals and companies desiring a profitable and safe investment.

By reason of the high efficiency of the luminous arc and the small cost incidental to its operation, a description of its applications to circuits other than those already described might be of interest.

The demand for a powerful and reliable railway headlight has increased rapidly with the extension of high speed interurban railroads. Until recently these requirements were fulfilled by the enclosed carbon arc headlight. The luminous arc, however, on account of its peculiar characteristics, has been developed and found ideal for this class of service.

The mechanism operating the luminous arc is not of a regulating type, but is so arranged as to strike an arc of a fixed length. With the slow rate of burning of the electrodes, there are sufficient interruptions of the circuit incidental to regular operation to maintain the arc within safe voltage limits. This permits of a more simple and substantial construction, which is suitable for railroad service as found in high speed interurban cars. The lamp, together with reflector, is held in place by a wing nut on the back of the casing, and can be readily removed for inspection or repair.

In order to protect the arc from air, which might otherwise get between the sections of and around the glass of the door, two separate panes are used, with the joints overlapped. The use of sections or slats instead of solid glass lessens the liability of breakage from extreme temperature changes.

The magnetite arc is at the focus of a highly polished metal reflector. The upper electrode is a "T" shaped copper forging, which, having a life of 2000 to 3000 hours, may be considered as non-consuming, and, being stationary, forms an arc which remains in the focus of the reflector. This upper electrode is held in place at the bottom of the draft chimney, where the natural draft keeps the arc burning on the electrode ends and carries off the fumes of iron oxide. The chimney is covered at the top by a hinged shield, so designed as to protect the arc from high winds and rain, and making the tubes easily accessible for cleaning. The lower electrode consists of an iron tube ½ in. by 5 in., filled with material which produces the necessary vapor in the arc stream to produce the luminous arc.

The track illumination is most satisfactory. The headlight not only illuminates the track for a distance of 1200 to 1800 feet ahead of the car, but the beam is exceptionally broad.

The lighting of a considerable area each side of the track is found to be of great assistance to motormen in approaching and taking curves, and is also an additional insurance against collision with vehicles, animals or persons approaching the track.

The luminous headlight is designed to operate at 75 volts and 4 amperes. The difference between the line potential and arc potential may be taken up in resistance. While the use of such a dead resistance gives satisfactory operation, incandescent lamps for lighting the interior of the car may be employed instead, thus utilizing the energy represented by the difference in voltage between line and arc. Different combinations of incandescent lamps can be used to make up this resistance, according to the number of lamps required to light the car. One very satisfactory combination is a group of sixteen 32 c.p., 110 volt lamps, consisting of four series of four lamps each, connected in multiple. If it is desired to increase the number of lamps in the car, thirty-two 16 c.p. lamps may be used, in eight series of four lamps each, connected in multiple.

If it is desired to keep these incandescent lamps burning when the headlight is removed, or while it is being transferred from one end of the car to the other, a substantial resistance unit may be employed, wired up to a pair of two-way snap switches, one being placed at each end of the car. This arrangement permits the headlight to be turned on or off without interfering with the incandescent lamp.

The vapors which render the metallic arc of high illuminating value, come from the negative electrode, so it is evident that in order to get this high candle power arc, the lower or composition stick must be negative. This peculiar characteristic may further be taken advantage of in the production of a dimmed light, where one is required for certain sections of the car route. With the current reversed and reduced to 2.5 amperes, a copper arc of low efficiency is produced, of an intensity suitable for city operation. This new headlight possesses the following advantages.

1st. The higher efficiency of the magnetite arc, giving quantity and quality of illumination.

2d. Arc maintained at focus of reflector, insuring permanent direction of rays.

3d. No enclosing globe used, thereby eliminating greatest expense of enclosed headlight maintenance.

4th. Long life of electrodes—2000 to 3000 hours for upper, 50 to 75 hours for lower—effecting a further reduction in operating expenses.

5th. Available means of quickly and effectually dimming the light—a modern method as compared with the use of screens hung in front of headlight door.

A modified type of this headlight has been designed for mining purposes. The internal mechanism and electrodes are the same as those used for street and interurban service, the principal difference being in the casing, which is of cast iron, and includes heavy cast iron doors for protecting the glass.

Where only a direct current power circuit of nominally 550 volts potential is available, very satisfactory arc lighting can be done, providing the line potential variation is not too great. Such a condition of line voltage may occur where connection can be made to the feeder circuit rather than to the trolley.

For any interior lighting, where the fumes from the center draft tube would be objectionable, the enclosed carbon arc lamp is recommended. A lamp is available for such circuits, as simple and reliable as that designed for direct connection to multiple 110 volt circuits.

The frame is of the parallel rod type, the rods firmly connecting the lamp top and base frame without intervening insulations—a modern and substantial construction. The magnets and the resistance are of the edgewise bare wire type, wound on edge and insulated with non-combustible silicate mixture. These windings are practically indestructible at any temperature which will not disintegrate the metal. To maintain the balance between the different lamps of the series; *i.e.*, to keep the arcs at approximately the same intensity, a simple swinging weight is used, having a varying effect for different positions of the regulating armature. This arrangement renders the lamp more reliable than any form using shunt winding for regulation. A shunt winding suitable for regulating an 80 volt arc and operating on a 550 volt circuit is liable to be burned out unless protected by additional cutout and cutout resistance.

For exterior lighting, or the lighting of machine shops, drill halls, train sheds, and for places where the fumes are not objectionable, the high efficiency luminous arc should be used. The lamp is of pleasing appearance and suitable size for installation on multiple circuits. The construction is similar to that of the enclosed power circuit lamp mentioned before, the prominent features of which are fireproof insulations, edgewise windings, and absence of shunt windings. In general, the lamp needs little attention; less, in fact, than the enclosed carbon type, as there are no enclosing globes and gas caps to require careful handling, cleaning and renewing.

If photometric or luminometer curves are examined, the increased illumination of the 4.0 ampere, 440 watt luminous arc as compared with either the A.C. or D.C. multiple enclosed arcs consuming 25 per cent. additional wattage, is evident. For street or park lighting the same ideal characteristic distribution is apparent. Where conditions require other distribution, this can be accomplished by the use of modern types of reflectors and diffusers.

ORNAMENTAL TUNGSTEN DIFFUSERS

By G. H. Stickney

The issue of the Review for May, 1908, contained a description of the tungsten economy diffusers which were then being placed on the market. These devices were designed in order to combine tungsten lamps into relatively large units and render them suitable for the illumination of wide areas in stores, factories, offices, etc.

Ornamental Tungsten Economy Diffuser with Plain Streaked Oxidized Copper Casing and 26 in. Art Glass Diffuser

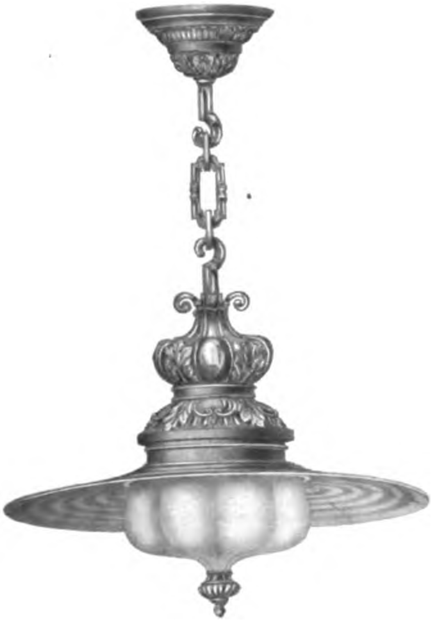
Tungsten Economy Diffuser of Ornamental Bronze, 26 in. Art Glass Diffuser

By careful study and experimenting it was found possible to produce a combination which not only avoided glare, and distributed an even intensity of light over a large working area, but which was withall remarkably econnomical of current.

These qualities have made the tungsten economy diffuser popular wherever a soft, even, general illumination is demanded. Experience has vindicated that feature of the design which eliminates the disagreeable glare of a bare incandescent filament, even at a small sacrifice of efficiency as expressed in candle-power per watt. And in this connection it should be noted that the candle-power, or foot candle, may often prove a misleading measure of the seeing value of a light or illumination unless these other elements are properly accounted for.

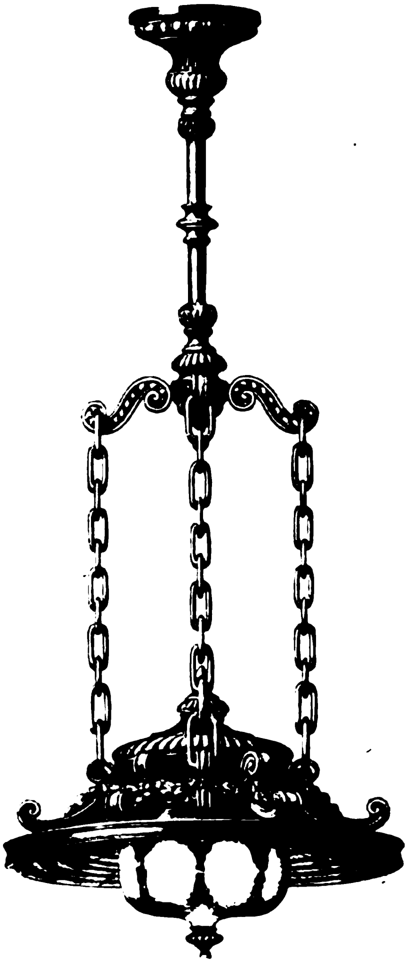
The diffused light from the tungsten economy diffuser not only makes it possible to see better than with a harsh light of equal intensity, but it gives a sense of pleasure and relaxation unobtainable with any intensity of glaring light.

In the design of the tungsten economy diffuser the key note was utility, and while the fixtures are neat in appearance, more emphasis was intentionally placed on those features which tend to produce excellent illuminating effects.



Ornamental Bronze Crown, 26 in.
Art Glass Diffuser

In applying the diffusers to actual installations they have been found particularly suitable for the class of lighting for which they were intended. On the other hand, it is apparent that there are many cases in which more elaborate and ornamental fixtures are required, even if at a considerably higher first cost, and, if necessary, at a sacrifice in efficiency.

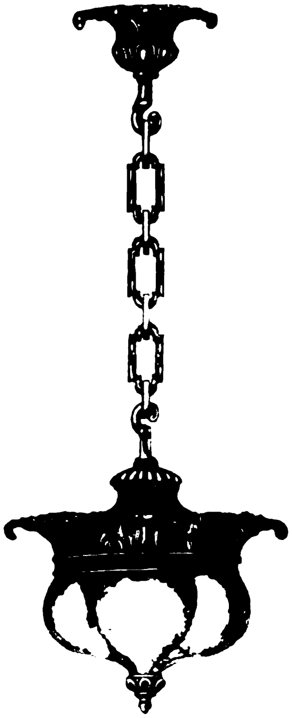


Ornamental Bronze Four Part Suspension
26 in. Art Glass Diffuser

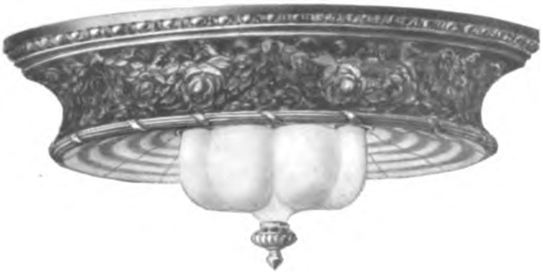
This field includes public buildings as well as the finer stores and offices, where the artistic decoration is considered important. In the past these places have been lighted from fixtures of more or less ornamental design, but very inefficient and ineffective as light producers.

Lighting problems of this nature having been presented to the Illuminating Engineering Department of the General Electric Company, the co-operation of artists experienced in Fixture Design was secured.

Together, these engineers and artists have fortunately produced a number of beautiful designs conforming to fundamental styles of decoration, and yet embodying the best illuminating engineering practice. Although designed particularly for special installations, the fixtures have been made suitable for general requirements. With a few additions, these designs compose the new line of ornamental diffusers which is now being placed on the market.



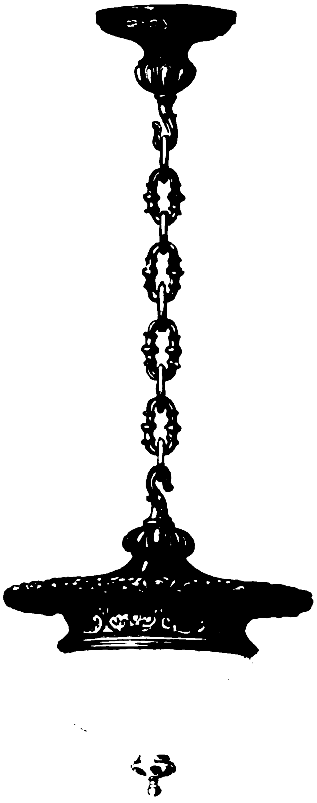
Onamental Bronze. No Diffuser



Ceiling Type Art Glass Diffuser and Cove

These fixtures are not only ornamental in appearance, both by daylight and when in use, but they are also effective and efficient as illuminants. In fact the ornamental diffusers are nearly as efficient as the ordinary line. What loss there is, is compensated for by the excellent diffusion, which is sufficient to satisfy the most severe demands.

The ornamental diffusers are of two principal types; namely, the five and six light units, and the single light units.

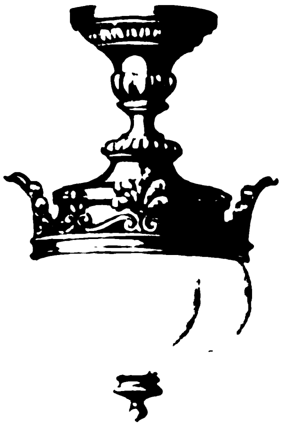


Ornamental Bronze. No Diffuser

The five and six light units have the same internal construction as the tungsten economy diffusers and can be used with 100, 60, 40, or 25 watt tungsten lamps, as described in the May, 1908, Review.

The new features consist of ornamental casings of various designs and modifications of diffusers and shades. The art glass diffuser, which is used instead of the steel, adds very much to the appearance of the fixture and permits a subdued light to be thrown on the ceiling; this gives a cheerful effect in the room. In some of the designs the diffuser is entirely omitted.

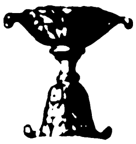
Either an art glass shade or a frosted shade may be used. The art glass entirely breaks up any image of the filament and, while it absorbs more light than the frosted shade, is beautiful in appearance and gives a more complete diffusion. Unless otherwise specified, art glass shades are furnished with "Ornamental" diffusers.

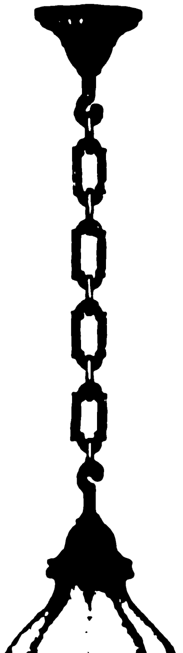

Ornamental Bronze; Ceiling Type; No Diffuser

Ornamental Bronze; Ceiling Suspension; No Diffuser

The single light diffusers were designed originally for the 250 watt tungsten lamp, but can be used effectively with the 100 watt size. They are so arranged that no glaring effect will be obtained, except by looking almost directly up at a lamp. Tip frosted lamps are recommended for use with this style of diffusers; all other styles take clear lamps.

The designs illustrated herewith have been standardized and can be furnished promptly. Specifications and prices are being sent to all the local offices of the General Electric Company. When some particular style of decoration must be accurately matched, special designs can be furnished. These will, however, require longer time for delivery, and unless ordered in large quantity will cost considerably more than the standard line.


Single Light Ornamental Diffuser; Ceiling Type; Art Glass Shade

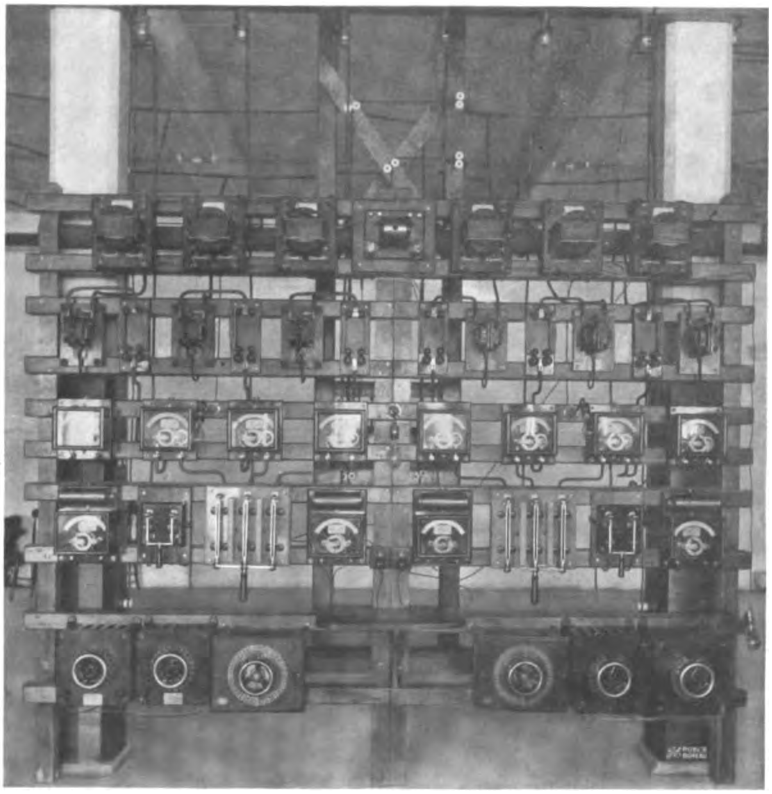

Single Light Ornamental Diffuser; Suspension Type; Lily Shape Shade

THE SWITCHBOARD

By A. B. Lawrence

The leading men in the profession today are those who, in the early eighties, operated the electrical apparatus then in use, and first recognized the economy, safety and reliability that were to be obtained by the proper control of electrical energy

At that time electrical knowledge was limited to a few individuals; the general public having little information as to matters electrical, and no conception as to the requirements of an electrical installation. It could not therefore be reasonably expected to appreciate the full advantages to be derived from a properly equipped switchboard.



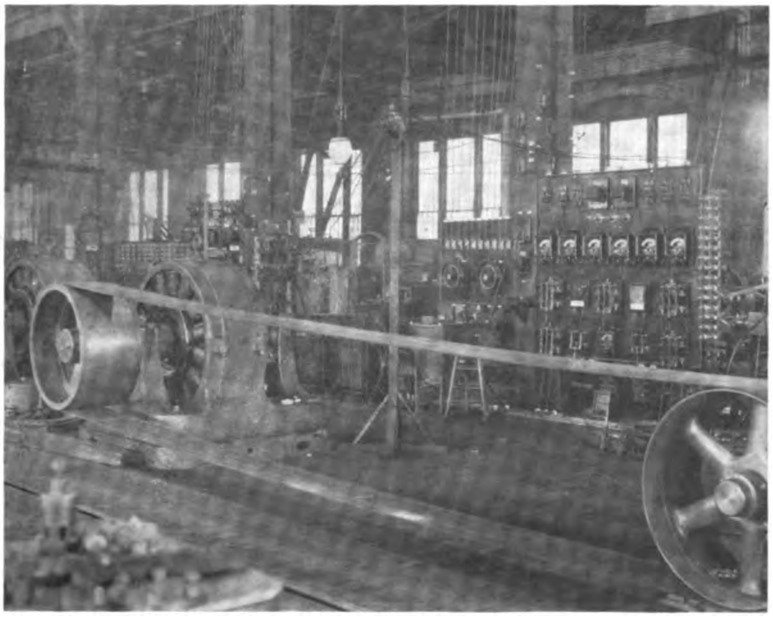
Early Type of Switchboard Showing Rack Construction

The illustrations given herewith emphasize the situation better than it can be expressed in words. The switchboard of this period has been aptly termed "the afterthought." It was the day of the small unit; there were no large electrical installations, and the switchboards, such as they were, had but one virtue—they did not cost much. They originated in necessity and there was no such thing as design.

The generator and exciter were installed; the station operator then found it necessary to use certain switches for opening and closing the circuits, and in some cases regarded it desirable to have instruments to indicate the voltage and amount of current being distributed. This was a much mooted question, however. on account of the extraordinary readings which would be procured by placing his instruments where they could be conveniently used. Instruments and meters were considered generally unreliable, and consequently unnecessary, inasmuch as the operator could never tell how they were going to operate until he had installed them among his wires and busses and observed their operation.

For the sake of convenience all switches and instruments were placed on the side walls of the building and put as close together as their dimensions would permit. The wires from the generators and feeders were then brought to the switches and instruments, and as additions were made, the number of wires soon became so great as to be a nuisance in operating the switches.

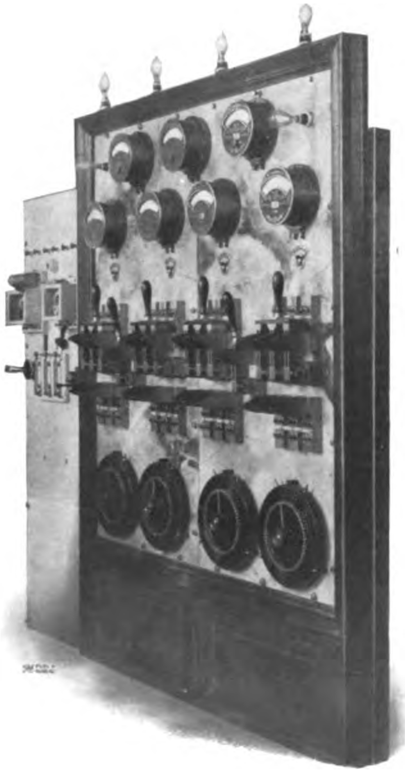
The next step in switchboard evolution occurred when the operator found it necessary to move his switches and instruments away from the wall a sufficient distance to make room for the wires leading to them. This was accomplished by the use of a plank or board on which the switches were attached; thus originated the name "switchboard." For a time the style of switchboards resembled that of a solid board fence, and necessitated a drilling of holes through the boards every time a connection had to be made. This inconvenience brought forth the switch rack, or lattice work, on which the switches and instruments were attached, allowing open spaces through which the wires could be brought. This switch rack and framework constituted a skeleton switchboard; some of these are still to be found in operation.



Primitive Wooden Switchboard

When additional generators and feeders were put in service, the operator would necessarily take a foot rule, measure the base of his switch, find a bare spot on his switch rack, and then fasten the switch upon it. After placing the switch, he would draw the wires over, under, and among the other wires behind the rack, until they reached the point for connection.

Little thought was given to safety or protection. The largest units operated did not exceed 500 kw. in capacity, and the highest voltage used was not above 2500 volts. The oil switch was unheard of. Some station operators were even skilled in the use of a contrivance consisting of a wooden handle in which was firmly fixed a stout leather strap or flap about six inches wide and eighteen inches long. In opening a feeder switch, the operator would take this strap in one hand, and at a single blow extinguish the arc which was pulled in opening a circuit.



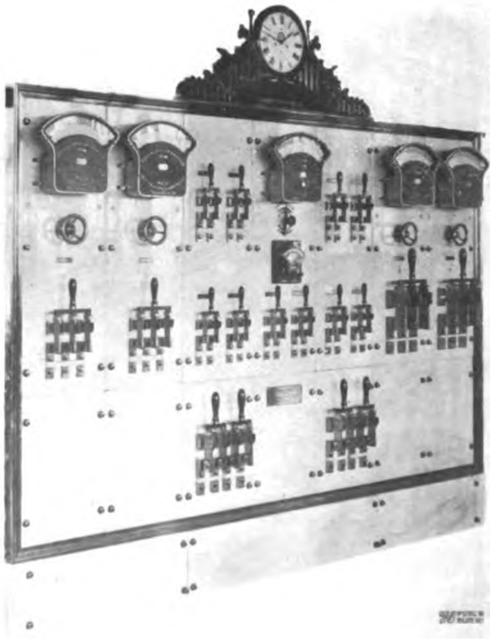
Old Style Switchboard with Elaborate Wooden Framework

Following the period of "afterthought" switchboards, came the period of "ornamental" switchboards, many of which were more ornamental than useful.

The character of the circuits and the magnitude of the units involved had not reached a point where switchboards became a very serious engineering question. Whenever a new alternating current generator was installed, a new exciter accompanied it, and no provision was made for paralleling either generators or exciters. The architect found in the switchboard the most likely object for artistic effort and consideration. The question of most economic operation and flexible control of energy was not given serious thought.

During this period switchboards were built of the rarer and more expensive woods, and occasionally of marble or marbleized slate. They were often set like a picture in a deep frame of metal or wood, or surrounded by large and ornamental scroll work, with massive clocks as center pieces. These clocks, by the way, were seldom wound, and emphasized more than ever the fact that switchboards were more ornate than useful during this period.

In those days individual units and small stations were subjected to the most severe fluctuations of load conditions. Their operation was necessarily very inefficient, and their meter and instrument indications very unreliable.



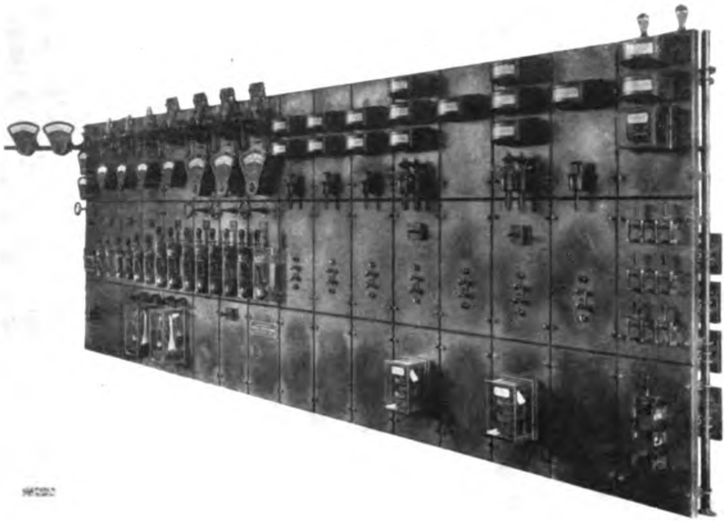
Early Type of Panel Switchboard, Unit Control

During the nineties the switchboard art had developed so far that the Thomson-Houston Company—now the General Electric Company—offered for sale, and its engineers recommended "panel units". This marked the beginning of the switchboard panel industry and the first appearance of slate panels. Switchboards were wired on the unit system, and some effort was made to provide for extensions and for the central control of large quantities of energy.

The introduction of the switchboard panel industry began a period which placed the switchboard in an entirely new atmosphere. It marked the beginning of the insurance stage of switchboard design, when the switchboard stepped in to take its place as a means of protection. In the natural course of evolution occasioned by the growth of generating apparatus and distributing systems, the old 200 and 500 kw. units were replaced by 2000 and 5000 kw. units. In place of a dozen small and electrically independent generating plants, we find central power stations with sub-stations so connected as to form one great electrical machine, all at the mercy of the switching and controlling system. With this evolution the old voltages of 1100 and 2300 volts were replaced by potentials of 5000 to 110000 volts; thus making possible the distribution of power over very great distances with a relatively small amount of copper wiring.

These great quantities of energy concentrated at single points would be useless and positively dangerous but for adequate means of controlling and switching; and thus the primitive "afterthought" switchboard has developed into one of the most important pieces of apparatus connected with electrical engineering.

The switchboard is the fundamental controlling point in the design of central stations. The amount of power generated and distributed is limited by the energy and voltage which the switchboard can safely handle. With rotary converters and storage batteries operating from the generators, it is impossible to control the generator by the exciter circuit as in the earlier days, inasmuch as the rotaries and batteries may feed back upon the system and do great injury, as well as involve great loss of energy. It has thus become necessary to be able to open the circuit when carrying full generating station output. It has been found expedient to provide automatic circuit opening devices for each feeder circuit and to permit the alternating current generators to operate directly on the busbars without automatic protection. With direct current generators, of course, the automatic protection is necessary.



Modern A.C. and D.C. Switchboard of Three Section Design

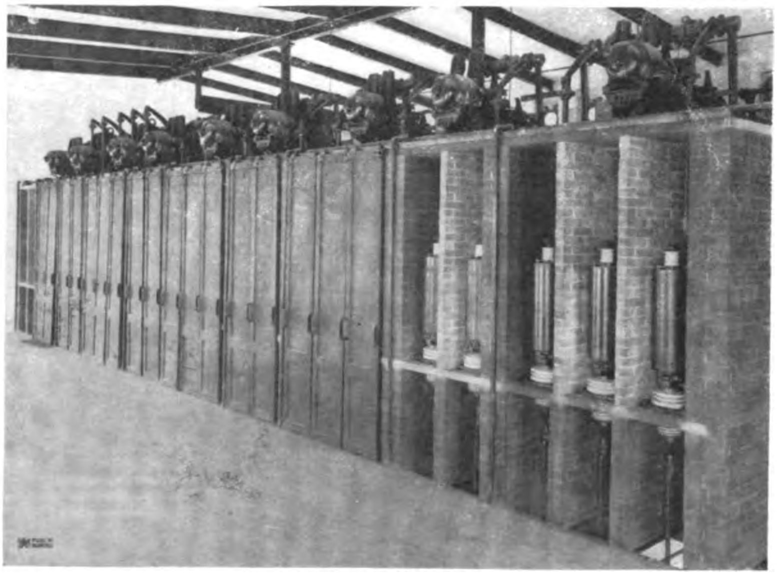
The high potentials and large amounts of energy dealt with in modern practice have called for the development of remote control switches and metering devices; that is, have necessitated the removal from the switchboard of all apparatus carrying the high potential currents, and precluded the bringing of any but secondary and control leads to the central operating board from which the system is controlled. With this situation existing today, we have the modern switchboards, which have passed through the many stages stated above, and may now be properly termed the "forethought," or one of the first considerations in every great electrical undertaking.

Upon the design of the switchboard today depends the safety and possibilities of the system. The switchboard is comparable to the switch tower of a great terminal railway system, where millions of dollars are at stake and may be instantly destroyed by a single failure to perform the functions imposed upon it.

2nd. There must be positive means for disconnecting every generator from the system, under all conditions of load.

3rd. Under most conditions of operation there must be automatic means of cutting off all current from a given line or section of the system during emergencies, as, for example, a short circuit.

4th. In systems of large capacity it is best to place the switches at a point remote from the switchboard itself, and often individually in fireproof compartments.



Electrically Operated High Tension Oil Switches Located in Fireproof Compartments. Remote Control

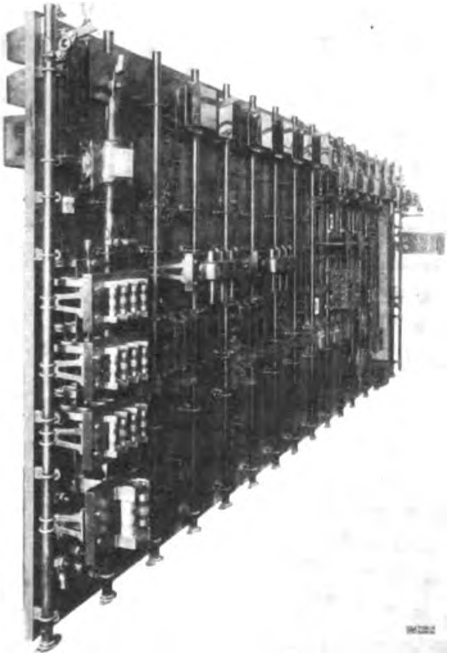
With the beginning of the year 1908 the General Electric Company placed on the market a line of switchboards consisting of some 15,000 different designs, all based on standard principles and developed through the experience of past years and in accordance with present requirements. These panels were subject to the most careful forethought; they have been tried and proven satisfactory; they are safe and can be relied upon to give full protection and to perform the functions for which they were designed.

The following general rules may be said to govern the design of modern switchboards:

1st. There must be means of positively disconnecting every feeder from the system, under all conditions of load.

5th. The whole switchboard must be constructed with special reference to preventing the spread of electrical trouble from one portion of the board to another. Bus bars must be so located that the probability of short circuits through carelessness is very remote.

In very large stations, as, for example, the Fisk Street Station of the Commonwealth Edison Company in Chicago, it is best to make the bus bars remote from the switchboard itself and install them in fireproof compartments, separating the negative and positive busses. Separation for the sake of protection is carried so far today that it is common practice to erect a separate building or structure for the high potential switches and bus bars. The bus bars are frequently sectionalized so that different generating units or feeders can be operated either independently or in conjunction with the main system.



Back View of Switchboard showing Wiring for Remote Control

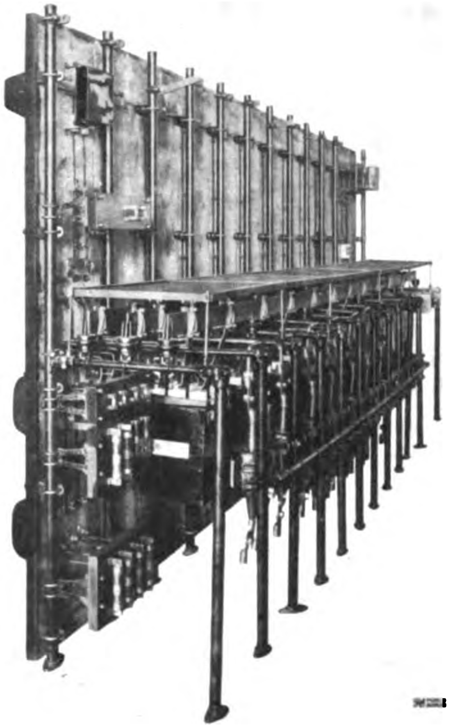
6th. All devices from which flashes or arcs might emanate, such as circuit breakers on direct current or low voltage alternating current boards, or expulsion type fuses, should be so placed that such arcs or flashes cannot start trouble.

7th. The use of all combustible materials should be strictly avoided; there should be nothing on or near the switchboard upon which flames could feed.

8th. In selecting the devices for use on a switchboard, the utmost care should be given to their proper insulation and to the extent of rupturing capacity, as well as current carrying capacity. It must be remembered that a switch ordinarily controlling a relatively small energy output will, in case of trouble, be called upon to open the entire generating capacity back of it.

The switchboard art has now developed so far that the General Electric Company has furnished to a number of its customers 110,000 volt alternating current, and 1200 volt direct current switchboards, fully equipped with indicating instruments, metering devices, switching and protective devices, of its own design and manufacture, that are capable of controlling and protecting the largest interconnected systems of electrical energy in existence.

The instruments, meters, transformers, lever switches, oil switches, circuit breakers lightning arresters, insulators, and regulating devices which have made the feats of modern electrical development possible, are in themselves subjects of exhaustive study and interesting detail. Suffice it to say that they have been tried and found satisfactory, and without them the electrical industry would revert to its primitive state; the great natural power resources of our country could not be utilized, and the generation and distribution of large amounts of electrical energy could not be undertaken.



Back of Low Tension A.C. Switchboard showing Bus Bars Protected by Shields

VARIABLE RATIO CONVERTERS

("Split Pole" Converters)

PART IV

BY CHAS. P. STEINMETZ

From equation (18) it will be seen that, in an n phase variable ratio (split pole) converter, the average armature heating is given by:

$$\Gamma = \frac{8\,s^2}{n^2 \sin^2\frac{\pi}{n}} + 1 - \frac{16\,s \cos\theta}{\pi^2} \qquad (18)$$

where

$$s = \frac{(1+t)\,(1+\lambda)\cos a}{\cos\gamma} \qquad (8)$$

$$\theta = \gamma - a - \beta \qquad (10)$$

and

t =ratio of third harmonic to fundamental alternating voltage wave.

λ =ratio of loss to output.

γ =angle of lag of alternating current.

a =angle of shift of the resultant magnetic field, in opposition to the armature rotation.

β =angle of shift of the brushes, in the direction of the armature rotation.

For a *three-phase converter* ($n=3$), equation (18) gives:

$$\left.\begin{aligned}\Gamma &= \frac{32\,s^2}{27} + 1 - 1.621\,s\cos\theta\\ &= 1.185\,s^2 + 1 - 1.621\,s\cos\theta\end{aligned}\right\} \qquad (19)$$

For a six-phase converter ($n=6$), equation (18) gives:

$$\left.\begin{aligned}\Gamma &= \frac{8\,s^2}{9} + 1 - 1.621\cos\theta\\ &= 0.889\,s^2 + 1 - 1.621\,s\cos\theta\end{aligned}\right\} \qquad (20)$$

For a converter of normal voltage ratio:

$t=0,\ a=0;$

with no brush shift,

$\beta=0;$

and when neglecting the losses,

$\lambda=0.$

therefore

$$s = \frac{1}{\cos\gamma}$$

$$\theta = \gamma$$

and equations (19) and (20) assume the form:

For three-phase:

$$\Gamma = \frac{1.185}{\cos^2\gamma} - 0.621$$

For six-phase:

$$\Gamma = \frac{0.889}{\cos^2\gamma} - 0.621$$

Equation (18) is the most general equation for the relative heating of the synchronous converter, including phase displacement γ, losses λ, shift of brushes β, shift of the resultant magnetic flux a, and the third harmonic t.

While in a converter of standard or normal ratio the armature heating is a minimum for unity power factor, this is not the case in general, but the heating may be considerably less at some lagging current, more at some leading current, than at unity power factor, or inversely.

It is interesting, therefore, to determine for what phase displacement the armature heating is a minimum, in order to be able to use this displacement as far as possible, and to avoid displacements differing greatly therefrom, which might produce excessive armature heating.

Substituting in equation (18) the values of s and θ obtained from equations (8) and (10), we get:

$$\left.\begin{aligned}\Gamma = 1 &+ \frac{8\,(1+t)^2\,(1+\lambda)^2\cos^2 a}{n^2\sin^2\frac{\pi}{n}\cos^2\gamma} -\\ &\frac{16\,(1+t)\,(1+\lambda)\cos a\cos(\gamma - a - \beta)}{\pi^2\cos\gamma}\end{aligned}\right\} \qquad (19)$$

$$\text{Let } m = \frac{n}{\pi}\sin\frac{\pi}{n} \qquad (20)$$

[which is a constant of the converter type, and, for a three-phase converter, is equal to 0.744; and for a six-phase converter, 0.955] and substituting in (19):

$$\Gamma = 1 + \frac{8}{\pi^2} \frac{(1+t)^2 \, (1+\lambda)^2 \cos^2 a}{m^2}$$

$$\frac{16}{\pi^2} (1+t) \, (1+\lambda) \cos a \cos (a+\beta)$$

$$+ \frac{8}{\pi^2} \frac{(1+t)^2 \, (1+\lambda)^2 \cos^2 a}{m^2} \tan^2 \gamma -$$

$$\frac{16}{\pi^2} (1+t) \, (1+\lambda) \cos a \sin (a+\beta) \tan \qquad (21)$$

Γ is a minimum for the value *0* of the phase displacement given by:

$$\frac{d\,\Gamma}{d \tan \gamma} = 0$$

which, differentiated, gives:

$$\tan \gamma_0 = \frac{m^2 \sin (a+\beta)}{(1+t) \, (1+\lambda) \cos a} \qquad (22)$$

For given values of a, β, t and λ, equation (22) gives the phase angle γ_0 at which the armature heating becomes a minimum.

Neglecting the losses λ, if the brushes are not shifted ($\beta = 0$), and no third harmonic exists ($t = 0$):

$$\tan \gamma_0{}^1 = m^2 \tan a$$

where $m^2 = 0.544$ for a three-phase converter
$= 0.912$ for a six-phase converter.

For a six-phase converter, $\gamma_0{}^1 = a$, approximately; that is, the heating of the armature is a minimum if the alternating current lags by the same angle (or nearly the same angle) as that by which the magnetic flux is shifted for voltage regulation.

From equation (22) it follows that energy losses in the converter reduce the lag γ_0 required for minimum heating; brush shift increases the required lag; a third harmonic decreases the required lag, if additive, and increases it, if subtractive.

By substituting (22) in (21), the value of the minimum armature heating of the converter is found, which can be produced by choosing the proper phase angle γ_0 for the alternating current. This becomes, after some transpositions:

$$\Gamma_0 = 1 + \frac{8}{\pi^2} \left(\left[\frac{(1+t) \, (1+\lambda) \cos a}{m} \right]^2 - \right.$$
$$2 \, (1+t) \, (1+\lambda) \cos a \cos (a+\beta) -$$
$$\left. m^2 \sin^2 (a+\beta) \right)$$

$$= 1 - \frac{8\,m^2}{\pi^2} \left(1 - \left[\frac{(1+t) \, (1+\lambda) \cos a}{m^2} \right. \right.$$
$$\left. \left. - \cos (a+\beta) \right]^2 \right) \qquad (23)$$

The term Γ_0 contains the constants t, λ, a, β, only in the square under the bracket, and thus becomes a minimum if this square vanishes; that is, if between the quantities t, λ, a, β, such relations exist that:

$$\frac{(1+t) \, (1+\lambda) \cos a}{m^2} - \cos (a+\beta) = 0 \qquad (24)$$

Of the quantities t, λ, a, β; λ and β are determined by the machine design; t and a, however, are equivalent to each other, that is, the voltage regulation can be accomplished either by the flux shift a or by the third harmonic t, or by both, and in the latter case can be divided between a and t so as to give any desired relations between them.

Equation (24) gives:

$$t^0 = 1 - \frac{m^2 \cos (a+\beta)}{(1+\lambda) \cos a} \qquad (25)$$

and by choosing the third harmonic t as a function of the angle of flux shift a, by equation (25), the converter heating becomes a minimum, and is:

$$\Gamma_0{}^0 = 1 - \frac{8\,m^2}{\pi^2} \qquad (26)$$

hence: $\Gamma_0{}^0 = 0.551$ for a three-phase converter.
$= 0.261$ for a six-phase converter.

By substituting (25) in (22), we get:

$$\tan \gamma_0 = \tan (a+\beta)$$

hence: $\gamma_0 = a + \beta$

or, in other words, the converter gives minimum heating $\Gamma_0{}^0$ when the angle of lag γ equals the sum of the angle of flux shift a and of brush shift β.

From this, it follows that, regardless of the losses λ, of the brush shift β, and of the amount of voltage regulation required, at normal voltage ratio as well as any other ratio, the same minimum converter heating $\Gamma_0{}^0$ can be secured by dividing the voltage regulation between the angle of flux shift a and the third harmonic t, in the manner given by equation (25), and operating at a phase angle between alternating current and voltage equal to the sum of the angles of flux shift a and of brush shift β. That is, the heating of the split pole converter can be made the same as that of the standard converter of normal voltage ratio.

Choosing $\lambda = 0.04$, or 4 per cent. loss of current, equation (25) gives for the three-phase and six-phase converters:

(1) No brush shift ($\beta = 0$):

$$t_3^0 = 0.467$$
$$t_6^0 = 0.123$$

That is, in the three-phase converter, a third harmonic of 46.7 per cent. would be required, which is hardly feasible; in the six-phase converter, a third harmonic of 12.3 per cent. would be required, which is quite feasible.

(2) 20° brush shift ($\beta = 20$):

$$t_3^0 = 1 - 0.533 \frac{\cos(a+\beta)}{\cos a}$$
$$t_6^0 = 1 - 0.877 \frac{\cos(a+\beta)}{\cos a}$$

for $a = 0$, or no flux shift, this gives:

$$t_3^{00} = 0.500$$
$$t_6^{00} = 0.176$$

As $\frac{\cos(a+\beta)}{\cos a} < 1$ for brush shift in the direction of armature rotation, it follows that shifting the brushes increases the third harmonic required to carry out the voltage regulation without increase of converter heating; thus is undesirable.

As seen, the third harmonic t does not change much with the flux shift a, but remains approximately constant and positive, that is, voltage raising.

From this it follows that the most economical arrangement regarding converter heating is to use a third harmonic of about 17 to 18 per cent. (a very large pole arc), for raising the voltage in the six-phase converter, and to regulate by shifting the flux (by the angle a) without greatly reducing the third harmonic; that is, keep a wide pole arc excited.

Since in a three-phase converter the required third harmonic is impracticably high, it follows that for variable voltage ratio work the six-phase converter is preferable, because its armature heating can be maintained near the theoretical minimum by properly proportioning t and a.

THE 110,000 VOLT TRANSMISSION LINE OF THE GRAND RAPIDS MUSKEGON POWER COMPANY

By David B. Rushmore
Engineer of Power and Mining Department, General Electric Co.

Considerable interest has been aroused by the 110,000 volt transmission line of the Grand Rapids Power Company which, now that it has been operating satisfactorily for five months, has proved the entire practicability of this voltage for long distance electric transmission of power. The line is insulated entirely by General Electric insulators of the disk type, and the following notes may be of interest.

The location of the line may be seen by reference to the map (Fig. 1). It runs between Grand Rapids and the Croton Dam, Michigan, and is fifty miles in length.

The line is carried on triangular steel towers which are approximately 53 ft. in height over all and 43 ft., 8 in. from the ground to the lowest cross arm, and which were designed to give a 40 ft. clearance between the line wire and ground. The towers (Figs. 4 and 5) weigh approximately 1700 lbs. each and provide a minimum spacing between the insulator hangers of 8 ft.; they are placed

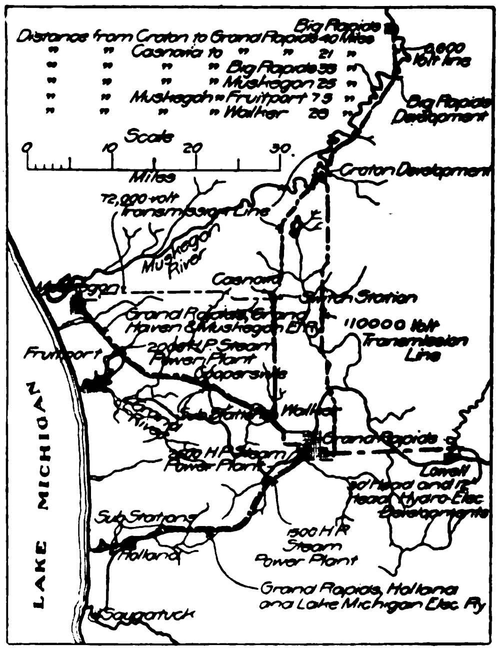

Distance from Croton to Grand Rapids 40 Miles
" " Cosnovia to " " 21 "
" " " " Big Rapids 55 "
" " " " Muskegon 25 "
" " Muskegon " Fruitport 7.5 "
" " " " Walker 20 "
Big Rapids
8600 Volt line
Big Rapids Development
Scale
0
10
20
30.
Miles
Croton Development
72,000 volt Transmission Line
Muskegon River
Muskegon
Cosnovia
Switch Station
Grand Rapids, Grand Haven & Muskegon El. Ry
110000 Volt Transmission Line
2000 H.P. Steam Power Plant
Fruitport
Coopersville
Walker
Sub Station
Grand River
Grand Rapids
2000 H.P. Steam Power Plant
Lowell
Head and Head Hydro-Elec Developments
Sub Stations
Holland
1500 H.P. Steam Power Plant
Grand Rapids, Holland and Lake Michigan Elec. Ry
Saugatuck
LAKE MICHIGAN

Fig. 1. Map Showing Hydro-Electric Development and Transmission Line of Grand Rapids Muskegon Power Company

on large concrete anchors buried in the ground, and are spaced 528 ft. apart on tangents. The anchors consist of 3 in. angle steel, 7 ft., 10 in. long, encased in concrete. The angles each extend about ten inches below the bottom of the concrete in which they are encased, thus securing a ground for the transmission line.

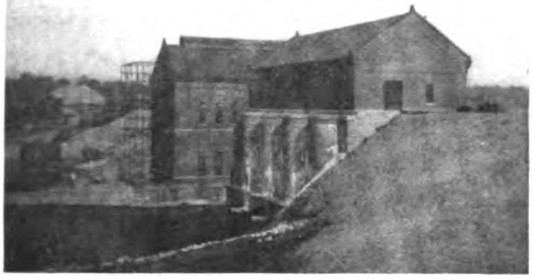


Fig. 2. Croton Dam Power Station showing Supporting Framework for Dead-ending Line

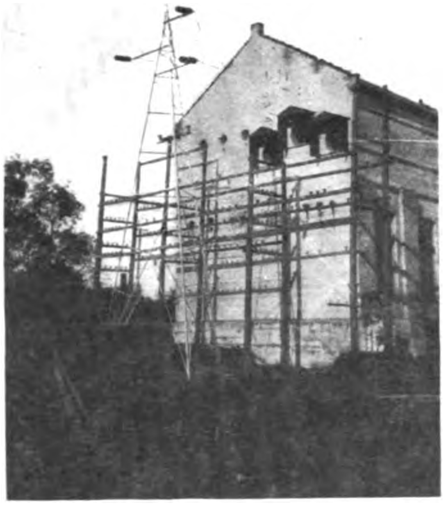


Fig. 3. Line Entrance to Grand Rapids Sub-Station, Grand Rapids

The majority of the right of way is located along the highways and only a tower right was taken. Where the line passes through forests or makes short cuts across country, a strip of land was purchased, varying in width from 33 to 66 ft., according to circumstances. This land is usually fenced off. No protection whatever is used where the lines cross highways or traffic routes.

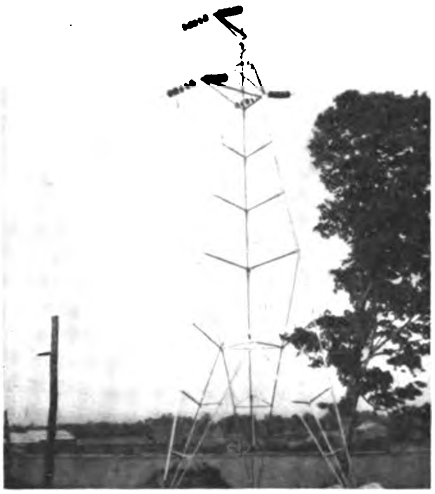


Fig. 4. Tower Showing Strain Type Link Insulator in Service

The insulators are of the standard General Electric disk pattern, the suspension type being used for a straight support and the strain type for pull-offs and curves. Five of these 10 in. disks are used in series, the arrangement being very clearly shown in Figs. 4 and 5. Each disk is rated at 25000 volts.

The line transmits 10,000 kw., the conductors consisting of No. 2 stranded hard drawn copper wire with hemp center. The lines are spaced 8 ft. apart and are entirely without transposition throughout the whole length. No guard wire is used.

The lines are brought into the stations through porcelain insulators and are connected directly to the high tension transformers, which are delta connected on both sides. There are no switches of any kind in the lines, the control being by means of generator field switches.

The pressure was first applied to the transmission line on July 18, 1908, and it was noticed that the line was a little noisy at the working pressure of 110,000 volts, while at night the atmospheric discharge was distinctly visible. Wattmeter readings on the 50 miles of empty line, after deducting the corelosses of the step up transformers, seemed to indicate a constant loss of from 20 to 25 kw.

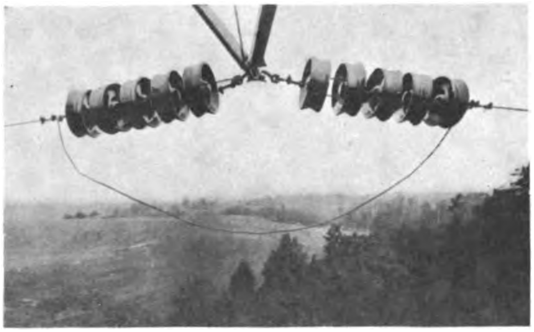


Fig. 5. Strain Type Link Insulators

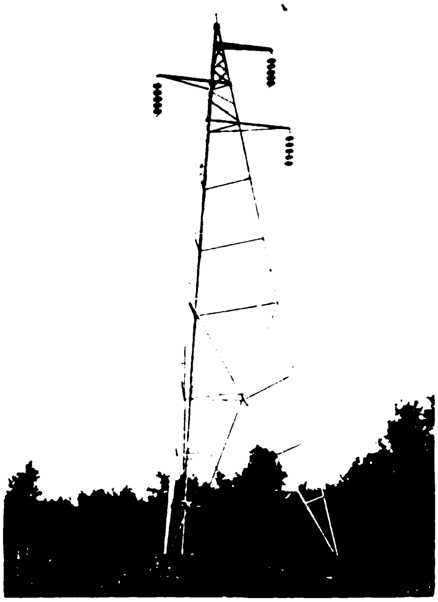


Fig. 6. Tower showing Suspension Type Link Insulator in Service

In view of the many troubles experienced by the large majority of companies when first putting in service high tension transmission lines, using tin insulators, the following statement, made by the Engineer of the Company, is of special interest: ". . . .the line has been in operation since July 18th last and we have experienced no trouble whatever; nothing of an unusual nature has occurred and we consider its operation as very satisfactory and successful."

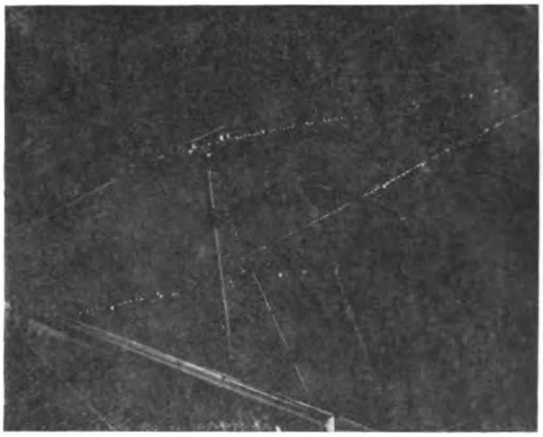


Fig. 7. Static Discharge from Line, as Seen at Night

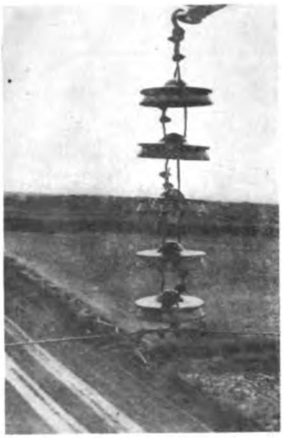


Fig. 8. Suspension Type Link Insulators

Some interesting features of the line are shown in Figs. 3 to 8 inclusive.

THERMODYNAMICS

PART II

By CHAS. P. STEINMETZ

Consider again the case of a mass m approaching a mass m_1, and suppose the mass m to consist of two separate masses m' and m'' (Fig. 1). These two masses will traverse slightly different orbits; the mass m' that approaches closer to m_1 reaching a higher velocity than the more distant one, m'', and therefore running ahead of it. This is what takes place when a swarm of meteorites or a comet passes around the sun; the separate masses no longer follow the same orbit, but diverge and separate, and in this manner the comet disintegrates and gradually vanishes.

If, however, the masses m' and m'' can not separate, but are held together by mutual attraction, the increased velocity imparted to m' causes the group $m' + m''$ to take a rotary motion.

Thus a molecule m, composed of atoms m' and m'', receives a rotary motion when swinging around the molecule m_1. The energy of this rotary motion is derived from the energy of the progressive motion of masses m' and m''. As separate masses, m' and m'' would continue their orbits with the respective velocities s' and s''; that is, with the energies of progressive motion $\frac{1}{2}\, m's'^2$ and $\frac{1}{2}\, m''s''^2$. Held together by mutual attraction, the group $m' + m''$ moves with the mean of velocities s' and s'', that is, with velocity

$$s = \frac{m's' + m''s''}{m' + m''}$$

Hence, with the energy of progressive motion,

$$\frac{m\, s^2}{2} = \frac{\frac{1}{2}\,(m's' + m''s'')^2}{m' + m''}$$

and this resultant energy of progressive motion differs from the sum of the energies,

$$\frac{m's'^2}{2} + \frac{m''s''^2}{2}$$

which m' and m'' would have as separate masses. The difference is transformed into rotary motion.

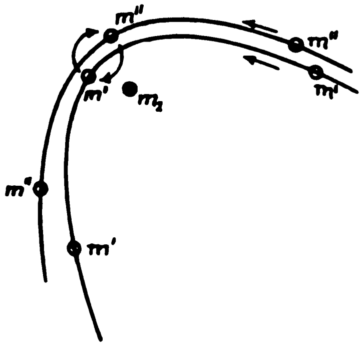


Fig. 1

If now the masses m' and m'', when approaching m_1, already have a rotary motion around each other, this motion is either increased or decreased by the rotary impulse given by the motion around m_1.

That is, when molecules consisting of several atoms,

$$m = m' + m'' + \ . \ . \ .$$

move around each other in their progressive motion, a transfer of energy takes place between irregular progressive motion and irregular rotary motion; that is, energy of progressive motion is converted into energy of rotary motion (or "intramolecular" energy, so-called because it is energy of motion of the atoms in the molecule), or energy of rotary motion is converted into energy of progressive motion, until, by the law of probability, an equilibrium is established between the energy of progressive motion and the energy of rotary motion.

That is, the heat energy, or energy of irregular molecular motion, consists of the energy of progressive motion of the molecules, and the energy of rotary motion of the molecules, or intramolecular energy; and a constant proportion exists between the two quantities of energy of irregular motion, the rotary and the progressive. This ratio of energy of rotary motion and of progressive motion depends upon the number of atoms in the molecule, and is the larger the greater the number of atoms per molecule; it obviously equals zero if the molecule consists of a single atom.

When impressing irregular energy upon a gas; that is, heating it, a part of the energy thus appears as progressive motion, $\frac{m\, s^2}{2}$, thus increasing the pressure p or the volume V; another part appears as rotary motion, or motion of the atoms in the molecule, U. The latter is the greater, the greater the number of atoms per molecule.

With increased heat, the velocity of motion of the atoms increases, and thus a critical velocity must occur which is sufficient to scatter them; the molecule thereupon disassociates. Thus in the molecule, chemical disassociation is the analagous phenomenon to evaporation in a liquid.

Internal and External Energy of a Gas

In a gas or vapor, we have, then, the following different kinds of energy of molecules, *viz:*

1. Energy of progressive irregular molecular motion,

$$M = \sum \frac{m\, s^2}{2} \qquad (28)$$

2. Energy of rotary irregular molecular motion, or intramolecular heat,

$$U = c\, M \qquad (29)$$

3. Position energy, that is, the energy representing the work done in separating the molecules of masses m by their distances r,

$$P = \int_{r_1}^{r_2} \frac{a\, m^2}{r_2^2}\, dr = a\, m^2 \left\{ \frac{1}{r_1} - \frac{1}{r_2} \right\} \qquad (30)$$

At the boiling point of a liquid, the molecular energy $\frac{m\, v_0^2}{2}$ is just sufficient to carry the molecules away from each other into infinity, that is,

$$\frac{m\, s_0^2}{2} = \int_{r_0}^{\infty} \frac{a\, m^2}{r_2^2}$$

$$= \frac{a\, m^2}{r_0} \qquad (31)$$

That is, at the boiling point, the energy of progressive motion of a liquid M, equals the position energy of the gas produced from the liquid at infinite volume, that is, infinite molecular distances.

In changing to a gas, at the boiling point, position energy P is therefore produced, and this energy is taken from the energy of irregular motion, M and U, in proportionate amounts, since $U = c\, M$.

In order that the gas shall have the same temperature as the liquid, energy must be supplied to restore the M, and therefore the U, to the same value as before.

When converting a liquid of temperature T_1 into a gas of temperature T_2, energy is required as follows:

First: To change the temperature of the liquid from T_1 to the boiling point, T_0; that is, to increase the energies M and U of the liquid.

Second: At the boiling point, T_0, if r_0' = mean distance of the molecules of the liquid, r_0 = the mean distance of the molecules of the gas at the same temperatures, the position energy,

$$P = \sum a m^2 \left\{ \frac{1}{r_0'} - \frac{1}{r_0} \right\}$$

is required to carry the molecules away from each other from distance r_0' to distance r_0 without changing their energies, M and U. Or rather, the molecules are carried away from each other from distances r_0' to distance r_0 by a conversion of energies M and U into position energy P, and the energy M and U, which has been thus expended, is to be supplied to the gas.

Third: When changing from a liquid of volume V_0', to a gas, of volume V_0, at the same pressure, p_0, the surrounding space has to be pushed away, that is, external work done, and thus the energy required is:

$$W = p_0\, (V_0 - V_0').$$

Fourth: To increase the temperature of the gas from the boiling point, T_0, to the temperature T_2, requires the following energies:

M_0'', to increase the progressive molecular motion or molecular energy.

U_0'', to increase the rotary molecular motion or intramolecular energy.

P_0'', to increase the position energy, by increasing the molecular distance from r_0 to r_2.

W_0'', to do the external work in increasing the volume from V_0 to V_2.

Assuming that a gas changes from a pressure p_1 and volume V_1 to pressure p_2 and volume V_2. At any moment, let p = pressure, V = corresponding volume. An increase of volume V by $d\,V$, against pressure p, then requires the energy,

$$d\,W = p\, d\,V,$$

and a change from p_1, V_1 to p_2, V_2 thus requires the expenditure of the energy.

$$W_1'' = \int_{p_1}^{p_2} p\, d\,V \qquad (33)$$

This is the external work done.

The heat energy of evaporation thus consists of position energy P, external work W, or is

$$L = P + W. \qquad (34)$$

This is called the *latent heat of evaporation*, since it is not felt, that is, does not result in a change of temperature. P is the *internal*, W the *external*, L the *total* latent heat of evaporation.

Specific Heat of a Gas

In a liquid, the energy required to raise the temperature of a unit weight by 1° is called the specific heat, c, of the liquid. It is definite, that is, depends only on the character of the liquid and the temperature, T.

In a gas, the specific heat, that is, the energy required to raise the temperature of a unit weight by 1°, is not definite, but depends upon the condition under which the temperature is raised. The gas equation is,

$$p\,V = R\,T,$$

and an increase of temperature T thus results in a change of pressure p, or change of volume V, or both; and depends upon the relative change of p and V. Thus different specific heats exist for a gas.

If, during the change of temperature, the volume remains constant, the pressure alone changing, the external energy, W, and the position energy, P, are zero, and only the molecular energy, M, and the intramolecular energy, U, are required.

That is, the specific heat at constant volume, c_v, is the molecular and intramolecular energy, $M + U$, required to raise a unit weight of a gas by 1° of temperature.

If, during the change in the temperature, the pressure remains constant but the volume increases, then in addition to the molecular and intramolecular energy, $M + U$, the position energy, P, is increased, by the increasing distance between the molecules and external work done;

$$W = p\,(V_2 - V_1),$$

That is, the specific heat at constant pressure, c_p, is the molecular energy M, the intramolecular energy U, the position energy P, and the external energy W required to raise the unit weight of a gas 1° of temperature.

That is,

$$c_p = c_v + P + W$$

For a given gas, M and U are proportional to each other.

The position energy, $P = \sum a m^2 \left\{\frac{1}{r} - \frac{1}{r^1}\right\}$, is proportional to M, since for $r' = \infty$, $P = M_0$, the energy M at the boiling point.

The external energy, $W = p\,(V' - V)$, is proportional to the temperature, and so the M. That is, all four energies are proportional to each other (with factors of proportionality depending on the number of atoms in the molecule), and the two specific heats, c_p and c_v, thus are proportional to each other.

In addition to c_p, at constant pressure, and c_v, at constant volume, an infinite number of specific heats, c_{pv}, exist, each defined by an equation existing between p and V during the change of temperature.

That is, if $f\,(p\;V) = 0$ is any function of p and V, the specific heat c_{pv} is the energy required to raise a unit weight of a gas 1° in temperature, while p and V change relatively to each other by this equation.

Expansion Curves of a Gas

A gas, as seen, has three variables, p, V and T, of which two are independent variables.

Any change of condition of a gas therefore is definite only if one independent equation is given between the three variables, p, V and T.

The most important of these conditions are:

A.

$$T = \text{constant},$$

that is,

$$p\,V = R\,T = \text{constant}; \qquad (35)$$

or,

p and V change in inverse proportion to each other, that is, the $p\,V$ curve is represented by an equilateral hyperbola.

This change at constant temperature, T, is called *isothermal*.

A change of gas at constant temperature leaves M, and therefore U, unchanged. With decreasing p and increasing V, the position energy, P, and the external work, $W = \int p\,d\,V$, are required.

That is, expansion of a gas at constant temperature, or isothermal expansion, requires energy output, the energy $P + W$. Inversely, isothermal compression of a gas requires abstraction of energy, or cooling.

B.

Change of p and V without input or abstraction of heat energy.

If, during the expansion of a gas, that is, the increase of volume V and decrease of pressure p, no energy is put into the gas, the energy $P + W$, required by the increase of volume, must be supplied by the internal energy $M + U$; that is, $M + U$ decreases, or, in other words, the temperature T—which is proportional to M—falls. That is, expansion of a gas without addition or subtraction of heat energy results in a decrease, compression in an increase of temperature. Such a change at constant total energy, $M + U + P + W$, is called *adiabatic*, or *adiathermal*. It is of foremost importance, since it is the change taking place in a gas when left to itself and doing external work in a heat engine, or receiving external work in a compressor.

The fall of temperature T results from the supply of energy P and W by the energy $M + U$. The smaller, therefore, the intramolecular energy U is, the greater must be the decrease of the molecular energy M; that is, the more the temperature T falls with adiabatic expansion.

The decrease of temperature T results in a decrease of volume, or of pressure, below that corresponding to constant temperature or isothermal condition.

That is, the adiabatic curve deviates the more from the isothermal the simpler the molecule of the gas is; that is, the less atoms per molecule it has. Assuming a gas of an extremely large number of atoms per molecule, the intramolecular energy U would be very large compared with the molecular energy M, and U would thus supply nearly all the energy $P + W$; that is, M, and thus the temperature T, would decrease very little with the adiabatic expansion, or the adiabatic curve would approximate the isothermal,

$$p\,V = \text{constant}.$$

With a monatomic gas, where $U = 0$, all the energy, $P + W$, must be supplied by M; that is, the temperature T falls most during adiabatic expansion, and the volume thus increases far less than it would on the isothermal curve.

To investigate these relations further, let

$c = \frac{U}{M}$ = ratio of the intramolecular to the molecular energy,

where $c = 0$ for a monatomic gas, as argon, helium, mercury;

$c > 0$ for a gas having several atoms per molecule, and the greater the larger the number of atoms.

Assuming unit weight of gas, of pressure p, volume V, temperature T; and let r = mean molecular distance, m = molecular mass, n = number of molecules per unit volume.

From the preceding equations, the change of the component energies, M, U, P, W, resulting from a change of volume $d\,V$, can then be derived; and as in adiabatic expansion, the total energy is constant, the sum of these changes of energy resultant from a change of volume $d\,V$, must equal zero. This gives finally the equation,

$$pV^{\frac{1+c+2/3}{1+c}} = \text{constant} \qquad (36)$$

The Equation of Adiabatic Expansion

$1 + c$ represents the energy of irregular molecular motion $M + U$.

$2/3$ represents the energy of position and of external work $P + W$.

The specific heat at constant volume, c_v, is proportional to $M + U$, hence to $1 + c$.

The specific heat at constant pressure, c_p, is proportional to $M + U + P + W$, hence to $1 + c + 2/3$, and the exponent, therefore,

$$\frac{1 + c + 2/3}{1 + c} = \frac{c_p}{c_v} \qquad (37)$$

or is the ratio of specific heat at constant pressure and at constant volume.

That is, the adiabatic curve is

$$p\,V^{\frac{c_p}{c_v}} = \text{constant} \qquad (38)$$

Denoting,

$$\frac{c_p}{c_v} = \frac{1 + c + 2/3}{1 + c} = a = \frac{M + U + P + W}{M + U} \qquad (39)$$

we have:

$$p\,V^a = \text{constant}. \qquad (40)$$

This is the equation of the adiabatic or adiathermal curve. The curve of expansion or compression without the addition or subtraction of heat energy; that is, the change in which the external work is done by or converted into molecular and intramolecular energy.

For a monatomic gas, $U = 0$, and therefore $c = 0$.

For a diatomic gas, as oxygen, nitrogen, air, carbon monoxide, etc., the energy of motion of an atom around the single other atom of the same molecule should be half the energy of motion of the atom around the two atoms of another molecule. That is, per atom, the intramolecular energy is one-half the molecular energy. That is, $U = \frac{1}{2}M$, or $c = 0.5$.

For a triatomic gas, as carbon dioxide, water vapor, etc., the intramolecular energy may be assumed as twice, for a 4-atomic gas, as ammonia, as 3 times that of a diatomic gas, that is, $c = 1$ for a triatomic, $c = 1.5$ for a 4-atomic gas, etc.

Hence,

monatomic gas	$c = 0$	$a = 1.667$, argon, helium, mercury.
diatomic gas	0.5	1.445, air, nitrogen, hydrogen, CO.
triatomic gas	1.0	1.333, CO_2, water vapor.
4-atomic gas	1.5	1.265, ammonia.
9-atomic gas	4	1.133, alcohol.

23 to 26 atomic gas, 11 to 12.5, 1.0555 to 1.0494, gasoline.

These relations between the numerical values of U and M, and the values of c and a, which are derived therefrom, do not strictly apply, however, if the atoms in the molecule are unequal in weight and if different forces act between the atoms of the molecule. Thus, for instance, in water vapor, H_2O, one of the atoms, O, has 16 times the mass of each of the other two atoms. This would have the effect, probably, of increasing the value of a, or decreasing U and c. The forces acting between the two H atoms and the O atom of the water molecule are, however, chemical forces, and the attraction between H and O is therefore greater than the gravitational forces. As a result thereof, the intramolecular motion of the atoms would represent a greater amount of energy than corresponds to the number of atoms, and U and c would therefore be greater than corresponds to a triatomic gas, that is, a would be smaller, and the more so the greater the chemical forces. Hence, elementary gases deviate less from the theoretical constants than compounds.

Unequal sizes of atoms, therefore, increase, chemical forces between the atoms (as in H_2O) decrease, the adiabatic constant a.

(To be Continued)

NEW PAY-AS-YOU-ENTER CARS FOR CHICAGO, ILL.

By L. G. Crawford

The rehabilitation of the electric surface railways in Chicago is making such a marked improvement in transportation that it is worthy of comment.

On November 1st., 1908, the Chicago Railways Company placed in service on West Madison Street the first of 650 "pay-as-you-enter" cars, which are the highest type of modern street cars, we believe, in existence.

The cars are 49 ft., 2 in. overall and weigh, with the electrical equipment, 53,000 lbs.; they seat forty passengers.

Six hundred of the cars, including the trucks, are being built by the Pullman Company, and the remaining fifty will be constructed by the Pressed Steel Car Company, at McKees Rocks, Pa.

The trucks are Baldwin type, modified in accordance with the Railways Company's specifications and called "Pullman No. 150."

DeClements fenders—the double basket type— are installed on each end of the cars, and from present indications they are one of the most common sense fenders that can be used on streets where the traffic is as heavy as in Chicago.

The principle of operation is, that if the first basket fails to catch, the object will roll under and lift the basket, thus automatically lowering the second basket to a point where it is almost sure to scoop up the body.

Each of the 650 cars is to be equipped with four GE-216, 50 h.p., 600 volt, commutating pole motors, two K-35 controllers, and such other parts as are necessary to make up a complete equipment, all of which will be furnished by the General Electric Company.

The motors and controllers are the first of their type to be used in Chicago, and so far have proven a decided success.

Commutating pole motors are especially adapted for railway service because of their good commutating and non-flashing qualities on the higher operating voltages, which are rapidly coming into favor on the larger electric railway systems. For a clear description of the commutating pole motor, I would refer to Mr. E. H. Anderson's paper read before the 26th Annual Convention of The Street Railways Association of the State of New York, held at Niagara Falls, June 30th and July 1st, 1908, a portion of which follows.

A semi-technical discussion of the problems and factors involved, and a careful study will assist the better understanding of the use and method of operation of the commutating pole motor.

Armature Forces

The simplest conception of an armature is a system of conductors so arranged as to produce a broad sheet of current under each pole parallel to the armature shaft, the direction of current under the north pole being the reverse of that under the south pole. Fig. 1 shows the development of the armature. The armature magnetizing effect changes the distribution of flux in the main pole face; this is shown in Fig. 2.

The maximum magnetizing effect of the armature occurs midway between the main poles, and this is where the current in the armature conductors is reversed in passing from the zone of one pole to the zone of the next. As the maximum magnetizing effect was between the poles a leakage flux was produced from the armature to the frame through the air space. In revolving, the armature conductors cut this flux and produce a voltage in the coil to be commutated. The leakage flux from the main pole tips acts in a similar way. The result is that a voltage is set up in the coil to be commutated, causing a local current to flow when the coil is short circuited by the brush during commutation. The local currents are thus added to the line current already in the armature conductors The greater current (line and local) surrounds itself with leakage flux, with the result that the current becomes more difficult to reverse during commutation.

Commutation in the non-commutating pole type of railway motor is secured by the increasing resistance of brush contact as the coil passes under the brush. The change of current in the armature coil surrounded by magnetic flux produces a kicking voltage. This voltage causes the current to continue to flow from the commutator bar to the brush, or vice versa, through the air, thus producing what is commonly known as sparking. Consequently a device is needed to counteract the sparking.

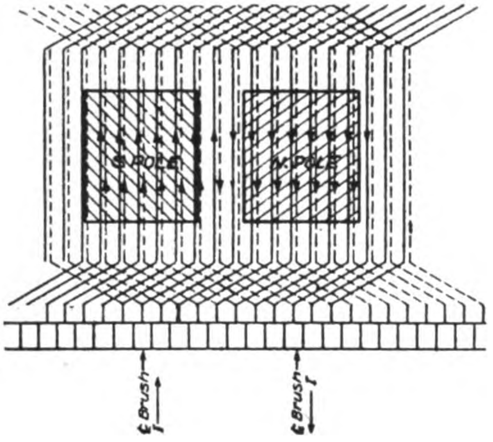


Fig. 1. D.C. Series Drum Armature, Thirty-three Slots and One Coil per Slot

We can put midway between the main coils a coil having the same magnetomotive force as the armature, but so connected that it opposes the magnetomotive force of the armature. If properly proportioned this would stop the leakage of flux from the armature to the frame and prevent the generation of local currents in the windings short circuited by the brushes.

There still remains the force necessary to reverse the line current flowing in the armature conductors. This can only be a potential of some two to ten volts, and to get it the conductors must cut a flux in revolving. This flux must come from the commutating pole, and it is produced by putting on the commutating pole core a few more turns than is needed to counterbalance the magnetomotive force of the armature.

The voltage thus produced must be sufficient to reverse the current in each armature coil as it is commutated, in the time that the brush is in contact with the commutator bars to which the coil is connected; thus when the coil leaves the brush, the current is flowing in the proper direction and in the proper amount. Under these conditions there is no tendency to spark and commutation may be said to be perfect.

The volts induced for commutation vary with the speed of the armature, and the commutating pole automatically takes care of commutation for any variation in speed, so long as the current in the armature and the flux density in the commutating pole face is constant.

Should we connect the commutating pole winding in series with the armature to vary the excitation of the commutating pole directly as the current in the armature, the proper relation will exist between the commutating pole flux, the volts induced, and the current in the armature to be reversed. Fig. 3 illustrates that the relation of commutating pole flux and armature current is a straight line; that is, it rises and falls directly with the current. As the proper commutating flux is provided at all speeds and currents it is possible to change the impressed voltage considerably without producing sparking.

It will be seen that commutating poles will allow designs of higher potential than that usually employed for street railway work. With clean commutators, 500 volts or more is required to jump across a single mica, but the limiting feature is the volts per bar which will maintain an arc already established. The voltage per bar which will do this depends largely on the surface conditions of the commutator.

Should the sparking be eliminated and the etching of the commutator bars very much reduced, on account of little or no local current being carried by the brush, the surface condition of the commutator would be very much cleaner and better in every way. Hence we can reasonably expect to use much higher voltage for commutating pole railway motors.

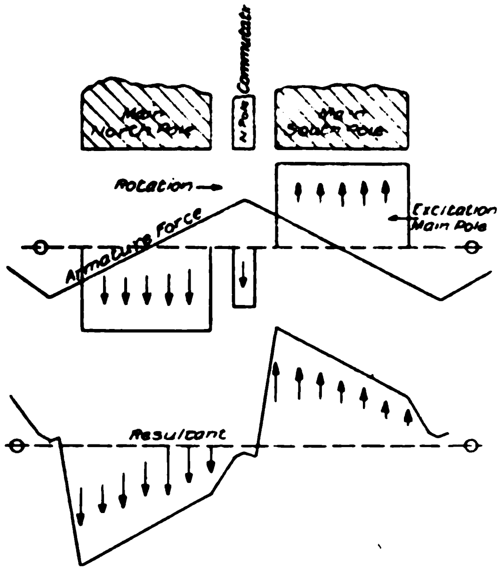


Fig. 2. Distribution of Main Flux in the Pole Faces

The K-35 controller is one of a type recently developed, and is provided with "bridge" connections by means of which full current is maintained through all motors during the transition period from series to parallel, thus obtaining a smooth acceleration and less strain on motors and gearing. Each contact finger is provided with an individual blow-out coil which produces a strong magnetic field for "blowing out" the arc between the segment and finger on breaking contact.

To say that the patrons using the Madison Street line are delighted with the new cars is putting it mildly, as the following open letter from one of them, printed in The Chicago Daily News of November 4, will show. I would particularly call attention to that part of the letter referring to the smooth acceleration.

"As I reside on the west side I enjoyed the delights of a ride down town in one of the new high-class "pay-as-you-enter" cars, introduced on the Madison Street line Monday morning. The new coaches are a vast improvement in every way over the smaller and usually crowded cars which have been in use on this greatest thoroughfare of the city. They are heavily built and the motors are powerful and quick to respond to the governing hand of the motorman. Furthermore, the new road bed and rails, just laid down, are massive and solid. Therefore the new coaches make good time without seeming effort, and are free from sudden jar and jostle. A seat in one of them is almost as comfortable as in one's own sitting room.

"Many a passenger looked about half in wonder, like a pleased child with a new toy; and everybody carried an air of comfort. Even those standing were not uncomfortable, apparently, since the car moved so easily there was no tossing about, as in the old cars.

"An unusual atmosphere of decorum pervaded the inside of the car—which is the most natural thing in the world, since new and well-appointed things always exert an influence for dignity and good behavior.

"The company should hasten the full equipment of the line, now that it has put on a few of these fine cars, for everybody will attempt to ride on the better cars, neglecting the old stand-bys which have done yeoman service so long.

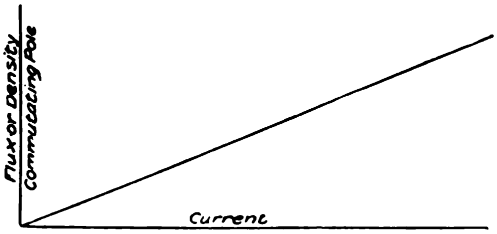
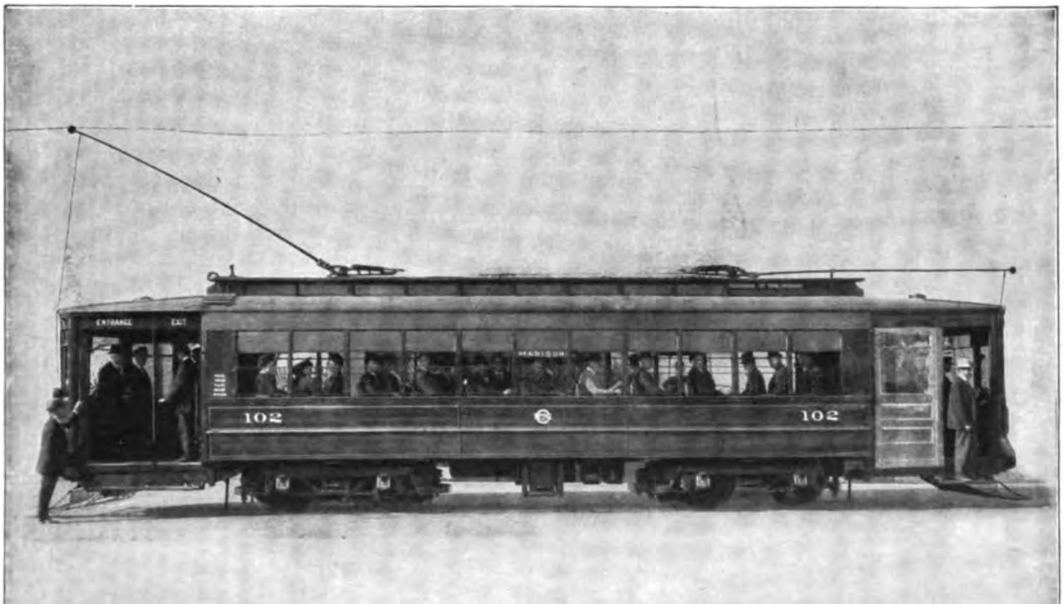


Fig. 3. Relation Between Commutating-Pole Density and Current

"What a wonderful change I have witnessed in Chicago's street-car service since I came to the city, a little more than two years ago! It is a far cry, indeed, from the small, old, worn-out cable makeshifts to the luxuriously appointed coaches, propelled by electricity, which are rapidly equipping every road in the city this autumn.

"Chicago says, 'I will,' and she does."



Chicago Pay-As-You-Enter Car

SPECIFIC HEAT OF GASES

By Maxwell W. Day

The specific heat of gases varies inversely as the atomic weight; that is, is proportional to the number of molecules rather than to their weight.

The specific heat for several gases at constant volume is as follows, the first column being for constant pressure and the second for constant volume. The third column gives the weight of one cubic meter of gas at 760 mm. pressure and 0° C. temperature. Multiplying the specific heat by the weight of one kilogram gives the specific heat per cubic meter at 760 mm. and 0° C. These figures are shown in the fourth column for constant pressure, and the fifth column for constant volume.

Dry Air	0.2375	0.1691	1.293	0.307	0.2186
Oxygen	0.2175	0.1551	1.430	0.311	0.222
Nitrogen	0.2438	0.1727	1.256	0.306	0.217
Hydrogen	3.409	2.4119	0.0896	0.305	0.216

It will be noted that the specific heat, referred to the cubic meter, is nearly the same for all these gases.

Assume that one cubic meter of dry air at 760 mm. and 0° C. receives 0.2186 calorie; its temperature will be raised 1° C., and if allowed to expand under constant pressure, will increase its volume by $\frac{1}{273}$. Assuming that this air is confined in a cylinder one square meter in cross section, it will push out a piston $\frac{1}{273}$ meter against atmospheric pressure, which is equal to 10,333 kilograms per square meter. The work done $\left\{\frac{10333}{273}\right\} = 37.8$ kilogram meters, and this divided by the mechanical equivalent of heat (=428), gives 0.0883 heat units. This represents the additional amount of heat necessary to be supplied to the air to provide for its expansion in addition to the 0.2186 heat unit for raising its temperature one degree.

$$\frac{0.0883}{0.2186} = 0.403,$$

and the sum of 0.0883 and 0.2186 is 0.3069. Therefore, it requires 40.3 per cent. more heat to raise the temperature of a given volume of air, if it is allowed to expand at constant pressure, than is required to heat it to the same temperature if it is confined to the same volume; that is, the specific heat of gases at constant pressure is about 40 per cent. more than the specific heat at constant volume. Very nearly the same figures apply to the other gases mentioned, and the ratio is usually given from 1.40 to 1.42 per cent.

NOTES

Mr. Henry B. Emerson, of the Power & Mining Engineering Department of the General Electric Company, has accepted the appointment of Electrical and Mechanical Superintendent of the Arlington Mills, of Lawrence, Mass. Mr. Emerson entered the testing department of the General Electric Company about sixteen years ago, and for the past ten years has largely devoted his time to industrial applications of electrical apparatus, in which subject he is a recognized authority.

Before his departure a farewell dinner was tendered to him by his associates, upon which occasion they presented him with a Riverside Maximus watch, bearing his monogram, and, on the inner case, that of the General Electric Company.

* * *

Mr. A. A. Tirrill, who has been with the General Electric Company for the past seven years, has resigned his position and will undertake the manufacture of small electrical supplies with a new Company in which he is interested.

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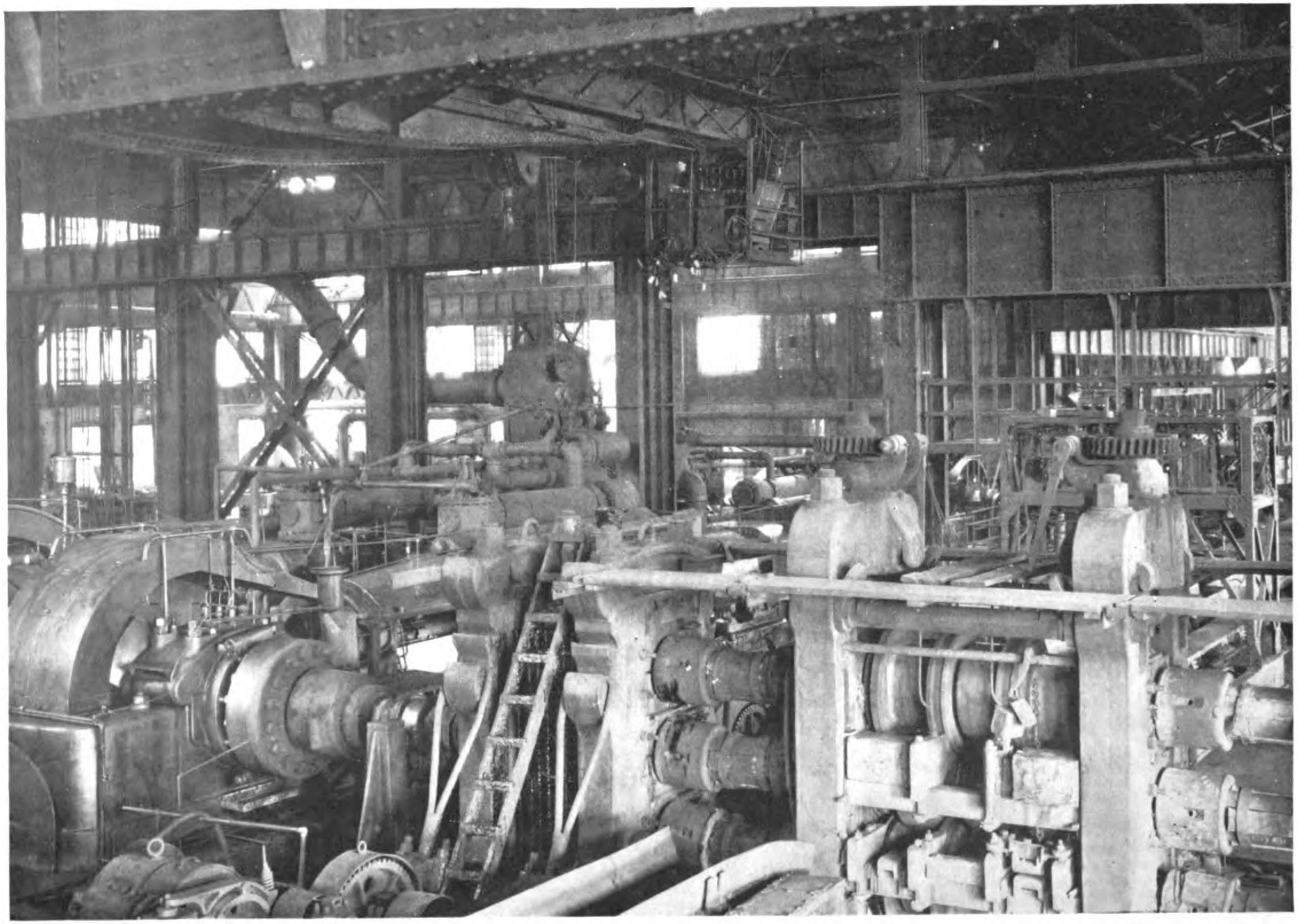

Finishing Rolls of Structural Steel Mill

GENERAL ELECTRIC REVIEW

ELECTRICITY IN STEEL MILLS

Electricity furnishes the most efficient and convenient means for the transmission of power over considerable distances. The energy available in blast furnace gas furnishes a source of power the utilization of which is necessitated by considerations of economic production; so that where blast furnaces and steel mills are in close proximity, the maximum employment of electric power throughout such works is both a natural and necessary result.

The problem as to the best method of utilizing the gas is being tentatively solved by the use of the gas engine. Conditions in steel mills are unique, and continuity of service is demanded above all else. Some steam power is, of course, necessary to start the cycle, and when considerations of first cost, repairs, depreciation, and reliability are taken into account, it remains to be proven that a modern steam turbine electric station, using the blast furnace gas under boilers for fuel, will not earn greater profits than the gas engine.

The electric drive of large rolling mills is new in this country. It requires electrical machinery especially designed for the purpose and a careful study of conditions; but no radically new functions are to be performed by the motors, and nothing but the most successful result can be expected. The many advantages of the induction motor will, in most cases, lead to avoiding the use of reversing mills; and for the same reason, the many minor and auxiliary operations in steel plants will be performed by an alternating current mill type motor.

The development of the mill type motor, alternating and direct current, has been brought about by the unusual requirements of this service, and will be used in every place where electric power to the extent represented by these sizes is applicable. While mill type motors are designed for the hardest service, the men who use them will gradually become educated to the desirability of giving careful attention to all electrical machinery.

Processes of manufacture are undergoing continual change, and it is not unlikely that the reduction of iron ore may some day be accomplished in a very different way. We are, however, even now at the threshold of a new departure in which a considerable amount of steel is to be made in electric furnaces.

The iron and steel industry is big in every way, and that its future will be associated with a large application of electricity will be a pleasure and a profit to all concerned.

DAVID B. RUSHMORE

Utilization of Blast Furnace Gases

No subject is of more vital interest to the Engineer of to day than the conservation of our coal supply. A marked advance in this direction is being made by the utilization of the waste blast furnace gases for furnishing power for operating steel mills. The total output from the blast furnaces of this country in 1907 was approximately 26 million tons of pig iron. The fuel equivalent of the waste gases resulting from the manufacture of this iron and available for power purposes, over and above that required by the blast stoves and to clean the gas, is approximately six million tons of good steaming coal.

Not long ago the steel mill engineer was in the discouraging position of realizing that these blast furnace gases, which represent mechanical power more than sufficient to complete the processes of manufacture from pig-iron to the finished article, were being wasted for lack of proper devices for their utilization.

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This knowledge has been one of the great incentives for the perfecting of the gas engine and the development of gas purifying devices.

Rotary Condensers

The conversion of the potential energy of these gases into electrical energy, and its transmission about the mill in the form of alternating current for driving the various rolls and auxiliaries by induction motors, affords the simplest and most efficient means of utilizing the available power. Because of the intermittent character of the load and the necessarily large air gap of the induction motors, the power factor of the system is low. The synchronous condenser affords a very inexpensive and efficient means of supplying the wattless component of the current, since it may be operated at a much higher speed than the generator units, especially if these are driven by gas engines, and may be located at the most desirable point in the system.

This use of rotary condensers is well recognized and they have come to be regarded as a necessary part of the equipment.

The article by Mr. A. L. Jones, appearing in this issue, should prove useful to those not actively following matters of this kind, all the more so since the explanations given are very simple and the point of view taken somewhat unusual. His conception of a rotary condenser as supplying excitation to the induction motor is not as baffling to one who has not made a special study of the subject, as the complicated explanations generally given.

Storage Batteries

Probably no power system is subjected to wider and more frequent fluctuations in load than one supplying power to a steel mill. The thermal efficiency of the gas engine has led to its general adoption as a prime mover in plants operated from blast furnace gases; but on account of its small overload capacity and the difficulty of operating generators in multiple when thus driven, a means must be provided for equalizing the load on the generators. A simple method of accomplishing this end is to allow a storage battery to float on the system through a split pole rotary converter or a motor generator set, as, on account of its ability to deliver large quantities of power for short periods of time, it furnishes an effective means of reducing the station load peaks to a minimum.

CEMENT MILLS

The disposal of blast furnace slag has until recently been a source of considerable expense to iron and steel manufacturers.

It was found, however, that this slag could be advantageously utilized as one of the ingredients in the manufacture of Portland cement, and very extensive plants for the production of this commodity are now being operated in connection with blast furnaces and steel mills.

These cement plants not only have the advantage of cheap raw materials, but also that of extremely cheap power; since the power available from the waste gases of the blast furnaces is much greater than that required for the operation both of the furnaces and of the steel mill using their product.

This excess power may be used to advantage in the cement mill, as it furnishes a practically constant twenty-four hour load.

THE ELECTRIC FURNACE

With the constantly growing demand for high grade coal and iron ore and the continued depletion of the deposits of these minerals, the metallurgists find it an increasingly difficult problem to meet the call for more and better steel. The difficulty in this problem is in no wise lessened by the justly rigid requirements of the railroad whose equipments are constantly endangered by the breaking of rails, due to poor materials and the severe strain incident to modern high speed traffic.

The ability to utilize raw materials that on account of the comparatively high sulphur and phosphorus content would be utterly unfit for use in the Bessemer converter, is tending to make the electric furnace a formidable competitor of the older forms of reducing and smelting apparatus. And when a device of only a few years standing, like the electric furnace, is able to compete, even under what are now special conditions, with the perfected results of a century's experience, it is reasonable to believe that the time is not far distant when these conditions shall have become normal and the electric furnaces have become as important and valuable a factor in metallurgical fields as are the many other applications of electricity in their respective spheres.

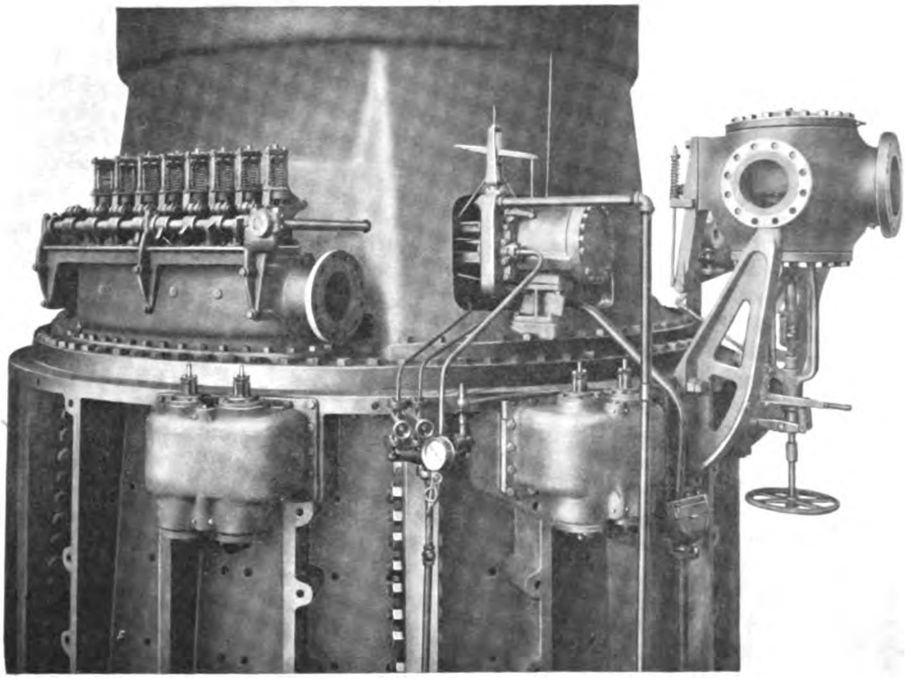
THE CURTIS TURBINE

By J. W. Kirkland
Turbine Engineering Department, General Electric Company

Ten years ago a steam turbine was rather a mechanical curiosity. To-day the largest and fastest ocean-going steamers are propelled by turbines, and the largest central electric power stations use them exclusively. In this short space of time, the turbine has achieved such success and has come into such general use that it takes rank with the steam engines and dynamo electric machine among the land marks of mechanical engineering. It has naturally been the subject of many historical sketches and engineering pamphlets; it has filled countless pages in the technical press and is the subject of several more or less complete and satisfactory text books. But all of these taken together give an inadequate idea of the rapid strides of its development and of the extent to which it has already come into use.

As it is the purpose of this article to deal only with the Curtis turbine, manufactured by the General Electric Company, it will be sufficient to call attention to what has been accomplished with it since the first commercial machine was completed so few years ago. The following statistics relate, therefore, only to Curtis turbines manufactured in Schenectady and Lynn.

Up to February first of this year there have been shipped and, for the most part, put in operation, more than 1200 turbines, having a combined capacity of 1,000,000 kilowatts. In addition to these, there were on that date about 200 machines on order and in course of construction, of which the combined capacity exceeds 200,000 kilowatts. These totals include:

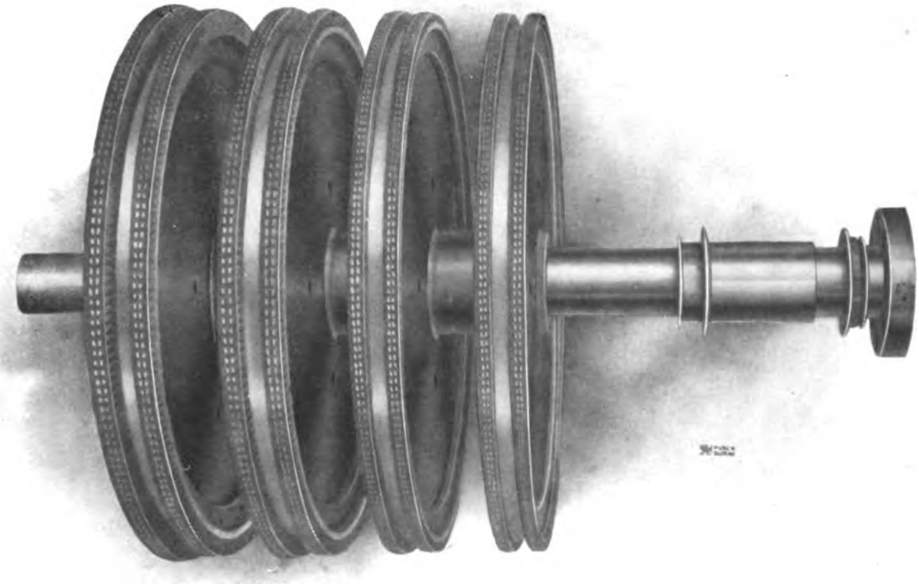


3000 Kw. Turbine, showing Hydraulic Controlling Cylinder and One Set of Valves

(About) 500 Turbines of from 500 kw. to 2000 kw.
" 90 " " " 2000 " " 5000 "
" 90 " " " 5000 " " 14000 "

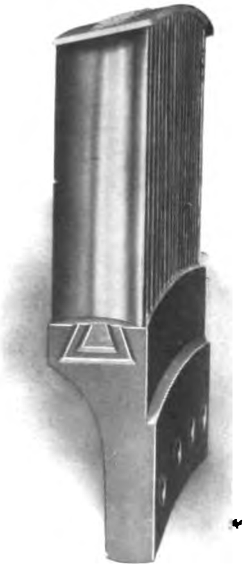
The number of machines of large capacity included in the total, shows in a striking way the extent to which this comparatively new prime mover has come into use.

Although its practical use began only about ten years ago, the steam turbine has already been the subject of many historical sketches, and of many more or less accurate text books. It is the purpose of this article to deal only with the Curtis type, as manufactured by the General Electric Company.



Rotating Wheels of 500 Kw. Curtis Turbine

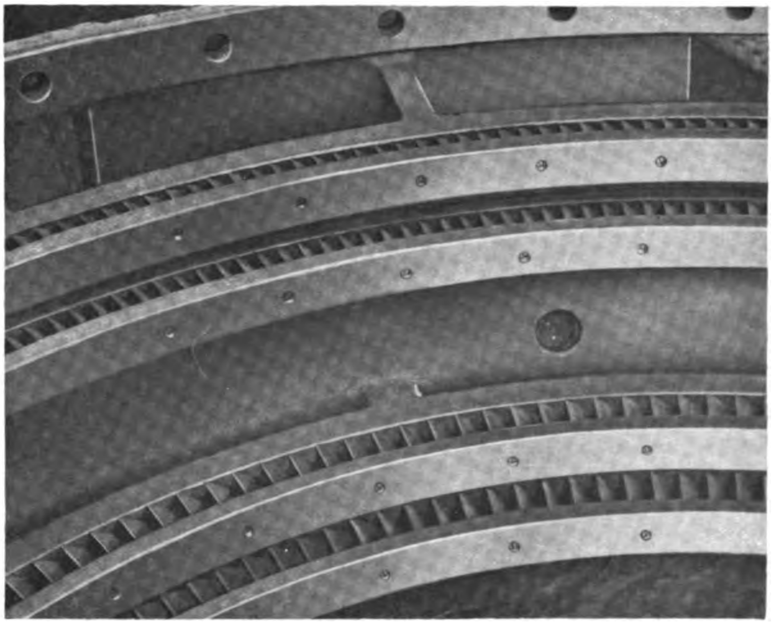
In this turbine, the principle of operation may briefly be described as the admission of steam to a steam chest, from which it passes through nozzles that are inclined at an angle with respect to a plane perpendicular to the shaft of the turbine. In traversing the nozzles, the steam expands and acquires velocity corresponding to the fall in pressure existing between the two extremities of the nozzle. Upon its exit from the nozzles it impinges upon the curved surfaces of revolving buckets carried by the first turbine wheel, and is thereby slowed down. It does not, however, part with all of its velocity and consequent energy to this wheel, but is redirected by a row of stationary buckets, which, reversing its direction, cause it to impinge upon the surfaces of a second row of revolving buckets carried by the same wheel that carries the first row. This description covers a two row per stage combination, but in certain cases three or some other number of rows of revolving buckets, with corresponding stationary or intermediate buckets, are used. When the steam leaves the last row of revolving buckets,



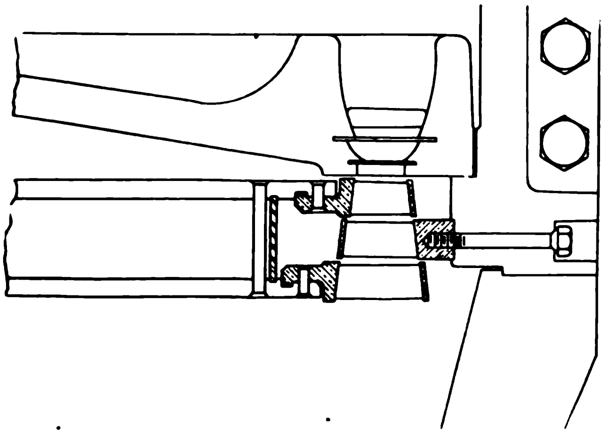
The Dovetailed Type of Bucket

its velocity with respect to a plane at right angles to the shaft is substantially nil and it has only the velocity of translation parallel to the shaft necessary to convey it to nozzles that admit it from the first stage into the second stage, where the arrangement of buckets is like that just described and where the process is repeated. This process continues through the several stages of the turbine, until the steam originally admitted to the high pressure steam chest has, by doing work, fallen in pressure and temperature to those corresponding to the back pressure in the exhaust connection leading from the turbine. The division of the turbine into stages and the use of more than one row of buckets per stage are for the same object; that is, the fractional abstraction of the available energy of the steam, so that the peripheral velocity of the wheels and their rate of revolution may be kept within convenient bounds.

As the steam passes from one stage to another, its specific volume is, of course, increased. This is provided for by increasing the height of the buckets and the number and the area of the nozzles in each stage with respect to the preceding stage. Therefore the steam chest occupies, with its nozzles, only about 20 per cent. to 25 per cent. of the area of the first stage wheel; in the next stage the nozzle area is greater and the individual nozzles larger; and so on until the nozzles in the last stage occupy the full periphery of the diaphragm and the area provided is sufficient to pass, with suitable velocity, the highly attenuated vapor corresponding to high vacuum.



First and Second Stage Intermediates of a 500 Kw. Curtis Steam Turbine after four and one-half years' continuous service



Diaphragm Nozzle and Buckets of Curtis Turbine

One important practical result attained by this design is that the buckets, both revolving and stationary, are necessarily of large size and substantial construction and are few in number.

The complete expansion of the steam in the nozzles and the maintenance of equal pressure on both sides of each revolving element eliminates all end thrust; in consequence, no thrust bearings or balancing pistons are needed on horizontal machines.

The same cause (complete transformation of pressure into velocity in the nozzles) permits large radial clearances between wheels and casings. Axial clearances, which in all turbines it is desirable to keep small, are limited by the unequal expansions of metal parts exposed to different temperatures. The short shaft length of the Curtis turbine has a favorable effect upon the limits of design in this respect.

The ability of a turbine to make effective use of high degrees of vacuum is of great practical importance. Steam worked from 150 lbs. pressure to 28 in. vacuum has 12 per cent. more available energy than if worked to 26 in.; if worked to 29 in. it has 10 per cent. more than if worked to 28 in. Owing to the large nozzle and bucket areas of the last stage of the Curtis turbine, these low ranges of expansion are used with exceptionally high efficiency.

The method of governing employed in a Curtis turbine is to vary the number of nozzle openings in the first stage, or, in other words, to vary, in accordance with the demands of the load, the area of the steam belt acting on the first wheel.

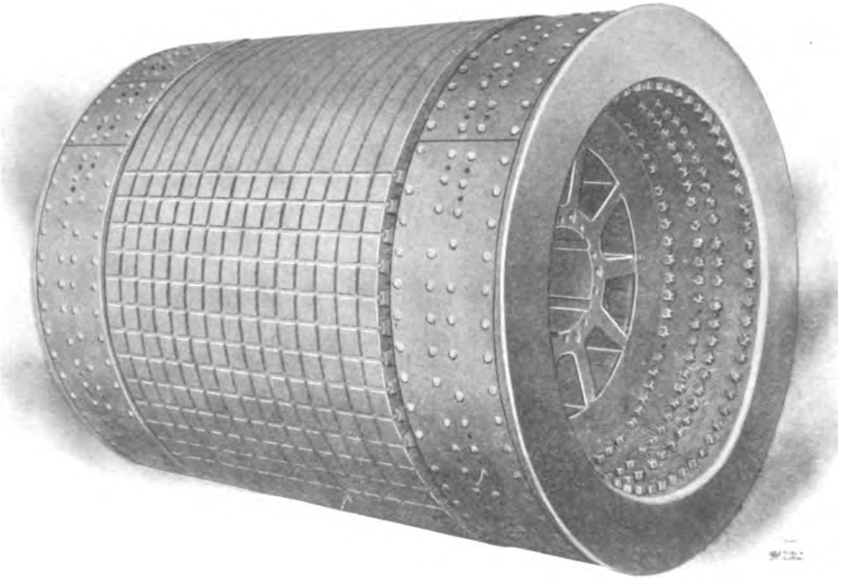
Such nozzles as are kept open and active by the governor work without throttling, and the loss due to throttling is thus confined to the single nozzle, which, under the action of the governor, may be at times full open, tight shut, or, for a short space of time, in an intermediate position. Throttling is always at the expense of efficiency, as has been clearly realized in the design of Corliss valve gears and other cut-off governing engines, and its avoidance in the Curtis turbine governor is of great benefit.

The Curtis turbine is built both horizontal and vertical. Each type of construction has its particular field, although to a certain extent these fields overlap. The different considerations governing this feature of design relate to possible speeds for the usual electrical frequencies in combination with the capacity of the machine considered.

The practical speeds for turbines are:

60 Cycles	25 Cycles
3600 (2-pole)	1500 (2 pole)
1800 (4 ")	750 (4 ")
1200 (6 ")	
900 (8 ")	
720 (10 ")	

For each speed the strength of available materials of construction limits the diameter of turbine wheels which may be employed. In general, high peripheral speed is favorable to steam economy.



Smooth Core Rotor for a 9000 Kw. Vertical Type Turbine-Generator

Without going into details, a consideration of these limits of design show that for large capacity and high speed of revolution a condition of stability is best secured by horizontal construction, while for slow speed in proportion to capacity, serious mechanical difficulties are avoided by vertical construction.

For example, a 3000 kw. machine at 1800 r.p.m. would be difficult to build vertical because of extreme height in proportion to base diameter; while a machine of that capacity at 750 or 720 r.p.m. is most economically built vertical.

Like all questions of engineering, it is one of selection and, to a certain extent, of compromise.

In essential features, the Curtis turbine is the same machine whether vertical or horizontal. Both types have the same arrangement of governor, nozzles, diaphragms, buckets and wheels. Space does not permit of a description of the machine in detail, but certain features of design should not be omitted in this article.

Wheels and Buckets

The wheels, of which there are two in each stage, are of rolled steel plate, turned to a smooth finish and to a section tapering from the hub to the rim on both sides. They are carried on the shaft by a hub and are separated one from another by a star shaped cast steel spider, the prongs of which extend well out toward the periphery. Near their edges they are separated by a cylinder of steel plate against which they are drawn by countersunk studs. At the edge the wheel is enlarged and drilled to hold the bucket rims, which are attached by countersunk rivets, set up by hydraulic pressure.

Buckets

The buckets are dovetailed into slots in the steel bucket rims, and are separated one from another by suitably shaped space blocks. Each rim, which is usually about 20 inches long, is assembled by itself, the steel of the rim being riveted over the end buckets. The buckets are of nickel bronze, extruded hot through dies under pressure and, after cooling, finished to a smooth, hard surface in steel dies by a hammering process. Each bucket has at its end a tenon which fits into openings in a steel cover plate. These tenons are riveted over the cover plate and the whole structure as completed is one of great rigidity and strength. Stationary or "intermediate" buckets and holders are made in the same general way.

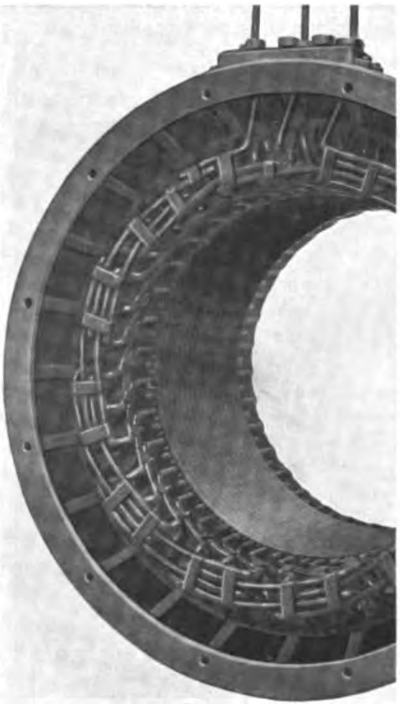
Packings

Carbon rings are used in stuffing boxes to prevent the leakage of steam from the first stage and also to prevent air leaking into the last stage. These rings, of special carbon, fit snugly to the shaft and to the sides of the box and are held in place by steam pressure. In a Curtis turbine, the pressure to be thus sealed against is only that existing in the first stage, which is about one-half the live steam pressure.

The packing of the diaphragm separating adjoining stages usually consists of a composition sleeve in which a labyrinth is turned.

Governor

This is of the centrifugal type. Its function is to control the delivery of oil under pressure to one side or the other of a piston in the valve-operating cylinder. The movement of this piston in one direction corresponds to a decrease of load and closes a suitable number of first stage nozzles by means of a rack running over a pinion carried by a cam shaft, the cams of which are so set as to open the valves successively. An opposite movement of the governor, and hence of the piston, reverses the operation. The oil under pressure for the governing action is in some cases supplied by the same pump that lubricates the turbine bearings, and in others by an independent source of supply.



Stationary Armature of 3750 Kw. Generator

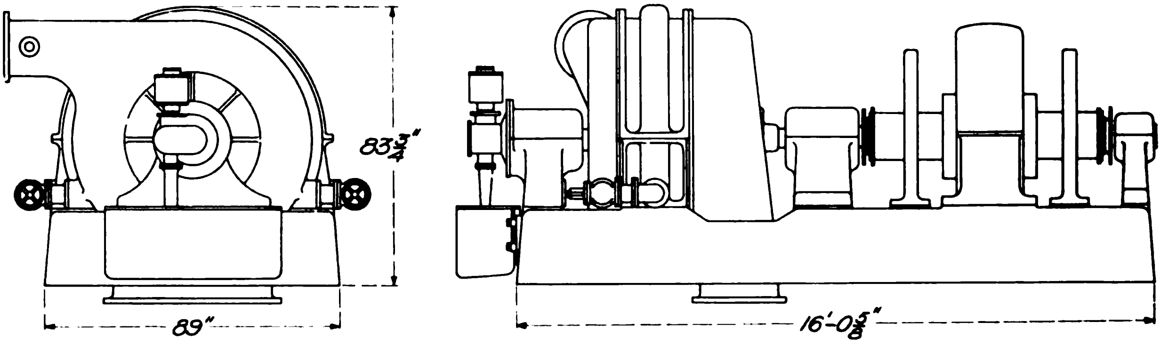
LOW PRESSURE CURTIS TURBINE

At this time very much interest is being taken in turbines designed to use steam wasted from non-condensing engines to atmosphere, or steam which is used with poor economy in condensing steam engines. The Curtis low pressure turbine is, except with respect to its method of governing, the same in principle and design as that which is designed to expand steam completely from boiler pressure to condenser pressure. As to governing, this is accomplished by throttling the steam, because nozzle control is not practical where, as in the case of such a turbine, the steam chest and nozzles must occupy a great portion of the first stage casing; and besides, in dealing with low pressure steam, comparatively little is lost in practice by such throttling.

So much has been written recently on the subject of low pressure turbines that it seems sufficient to state quite briefly their purpose and their effect upon the two fundamental considerations of a power plant.

Peak Capacity and Efficiency

Steam at atmospheric pressure has about as much available energy when worked down to fairly good condenser pressure, say 2 in. of mercury, as has steam at, say, 150 lbs. when worked down to atmospheric pressure. In a non-condensing engine this energy in the lower pressure range is thrown away. In a condensing engine it is used to such poor advantage that the improvement in economy obtained by operating condensing is only about 25 per cent. as compared with exhausting to atmosphere; the result being that in many cases it does not pay to install and operate condensers.



Outline of 500 Kw. Horizontal Low Pressure Turbine

A low pressure turbine transforms this low pressure energy with such high efficiency that when installed with a condenser in connection with a non-condensing engine, it practically doubles the output *without any additional fuel cost*, and increases peak capacity by 100 per cent. *without additional boilers*, and this almost always *without additional engine room space*.

When installed with a good compound condensing engine, it will improve the steam economy (as compared with ordinary condensing operation) by about 25 to 30 per cent., and will increase the peak capacity by from 60 to 100 per cent., depending upon the engine.

When used in connection with rolling mills or hoisting engines, a low pressure turbine will, if installed with a suitable heat storage device or "regenerator," give a large amount of power without any fuel or boiler cost. A good sized blooming mill engine, having cylinders say 52 by 66 in., will generally give enough steam to run a 1500 kw. low pressure turbine, with a very insignificant drain of steam at boiler pressure during the temporary stoppages of the reversing mill engine.

MIXED PRESSURE TURBINES

In a Curtis turbine it is not necessary to use the whole periphery of the first stage for low pressure steam nozzles. A section can be partitioned off and equipped with special expanding nozzles to receive steam at high pressure direct from the boilers. Such nozzles deliver their steam against the same wheel as do the low pressure nozzles, but occupy only a small portion of its periphery. The steam is expanded in these nozzles from high pressure all the way down to the normal pressure of the first stage, and in such expansion acquires a high velocity and consequently contains a great deal of energy—much more than does an equal quantity of low pressure steam. In consequence of this, high pressure steam is used with a far lower water rate than is obtained with low pressure steam, or with high pressure steam reduced to low pressure in a reducing valve. This construction, which is peculiar to the Curtis turbine, is called "mixed pressure." Its function is the same as that of the reducing valve; *i.e.*, it makes up for a deficiency of low pressure steam by drawing direct on the boilers; but it does so without the annoyance and uncertainty of a reducing valve and with an economy about one third better. That is, a mixed pressure turbine requiring, for example, 34 lbs. of low pressure steam per kilowatt hour will require only about 22 lbs. of high pressure steam per kilowatt hour.

With this construction, the full power of the turbine can be developed with:

All low pressure steam.
All high pressure steam.
Any necessary proportion of steam of each pressure.

Furthermore, the transition from all low pressure to all high pressure, through all the conditions intermediate between these extremes, is provided for automatically by the turbine governor; a deficiency of low pressure steam causes the high pressure nozzles to open automatically.

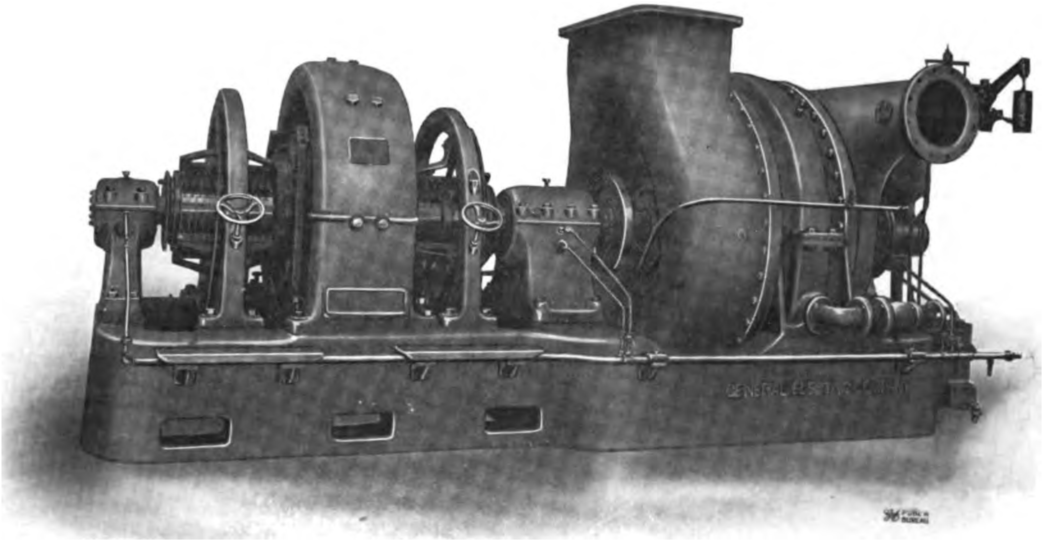
With this arrangement it is not necessary for purposes of economy to proportion exactly the low pressure turbine to the amount of exhaust steam available, but, within obvious limits, it may be made as large as the load demands.

Curtis turbines of this type are being built in a large range of sizes, and it seems certain that they will in many instances offer a good solution of problems where, for lack of constant exhaust steam supply, simple low pressure turbines have been considered of doubtful utility.

In this country we have been rather slow to appreciate the possibilities of the low and mixed pressure turbine; but abroad, in England and on the continent, where the comparatively high cost of coal has been a strong spur, a great deal has been and is being done along these lines at this time. Independent companies have been formed to secure exhaust steam from mills and mines for the purpose of developing electricity to sell to users of power. It is thus treated as it should be—like so much potential energy, a coal deposit or a water fall.

Exhaust steam might in effect be considered to be one of our natural resources which is now going to waste. Imagine a waterfall of thousands of horse-power; located in the midst of a manufacturing community; with no incumbrances such as the need of special powers or privileges from a legislature; with no riparian rights to be considered; no land to be bought; and a cost of $35 per horse-power to develop. How long would it be before such a water power would be developed? If such ever existed it has long since been put to work and is earning good dividends to-day.

But there are similar chances for profit *from exhaust steam* wherever you turn. They are not so spectacular as water powers, but they are just as real.



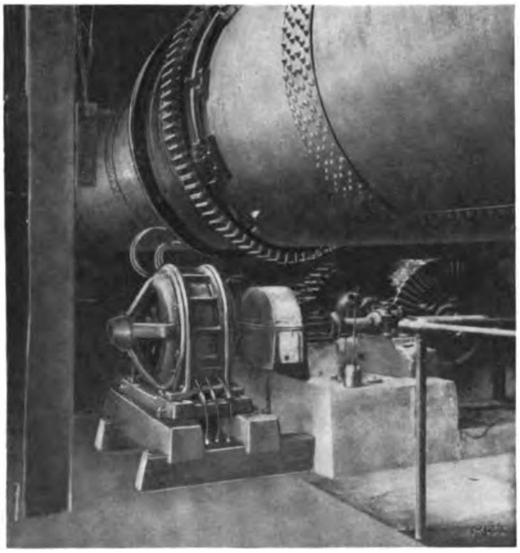
500 Kw. Horizontal Low Pressure Turbine

ELECTRIC DRIVE IN CEMENT PLANTS*

By C. C. Batchelder

Power and Mining Engineering Department, General Electric Company

Since the first application of electric drive in mills, early in the '90's, the system has advanced rapidly through the experimental stages, and, by its practical superiority, has attained a position above that of any other method of distributing power in manufacturing establishments. Some industries now have few, if any, representative plants that are not electrically driven, this being notably true of textile and cement mills.



18 H.P. Induction Motor Driving Rotary Kiln

Electric drive bases its appeal for favor on its efficiency, ease of manipulation, reliability, and low maintenance costs, and the extent to which it is used in various industries depends on the importance attached to a consideration of these factors. The advantage derived from increased efficiency is directly proportional to the ratio of the cost of power consumed in the manufacturing process to the total cost of the finished product. The greater the part played in this cost by fixed charges, such as taxes, interest etc., the more important becomes the question of reliability. In an industry such as the manufacture of cement, where the raw materials are extremely cheap and the labor charges comparatively slight, the importance of keeping the power required as low as possible, and of getting the maximum output from a plant, once the investment is made, combine to make the use of electric drive almost imperative. The making of cement today probably owes more to, and is more dependent on electric drive than any other industry.

In the last twenty years cement manufacture has experienced a rapid but apparently healthy growth that has raised it from the infant industry class to a position among the largest and most important manufacturing interests. Cement is a product the uses and properties of which are much more widely known than the processes employed in its manufacture, partly, no doubt, because the latter lack the spectacular features present in some industries. However, in spite of its many unattractive points, cement making is of great interest to electrical engineers, both on account of the size of field it affords, and because of the fact that it presents a number of features which must be known and carefully considered before electric drive can be applied to the greatest advantage.

Portland cement is a product of somewhat variable chemical constitution, but consists essentially of calcium silicate and aluminate, with traces of iron and magnesium. An analysis shows, roughly, about 62 per cent. calcium oxide or lime, 8 per cent. alumina and 21 per cent. silica, with the remaining 9 per cent. made up of iron oxide, magnesia and sulphuric acid. The raw materials used in its manufacture are of two classes, the one rich in calcium in the form of carbonate, such as limestone, marl and chalk, and the other containing silica and alumina in larger proportions than is found in the finished product. The latter class includes such materials as clay, shale, slag and natural cement rock. The particular raw materials used determine the first steps in the manufacture of the finished product, the object being to obtain an accurate and intimate mixture of the ingredients in the proper proportion. In the majority of American plants, the raw materials are either limestone, and clay or shale, with the first forming the larger part of the mixture, or cement rock or blast furnace slag enriched in calcium by the addition of high grade limestone. With any of these combinations of materials the method of manufacture is known as the dry process. There are, however, a number of plants in operation which use marl for the lime bearing ingredient and soft clay for supplying the necessary silica and alumina, and as these are both usually wet when found, it is simpler to leave them so during the preliminary steps of grinding and mixing; whence the name of "wet process" given to this method. In both classes of plants the burning and subsequent grinding processes are the same.

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* Paper presented before the Toledo Section A.I.E.E. Jan. 15, 1909.

In the dry process the raw materials must be crushed, and after being mixed in the proper proportions, thoroughly dried and pulverized. If the wet process is used, the ingredients are mixed, usually in revolving pans, and further reduced in pulverizing mills. In either case the raw material is next burned, this being accomplished in rotary kilns in all modern plants. These kilns are long steel tubes lined with highly refractory clay or fire brick, and are sometimes constructed as large as 180 ft. in length, with an internal diameter of 10 or 12 ft.

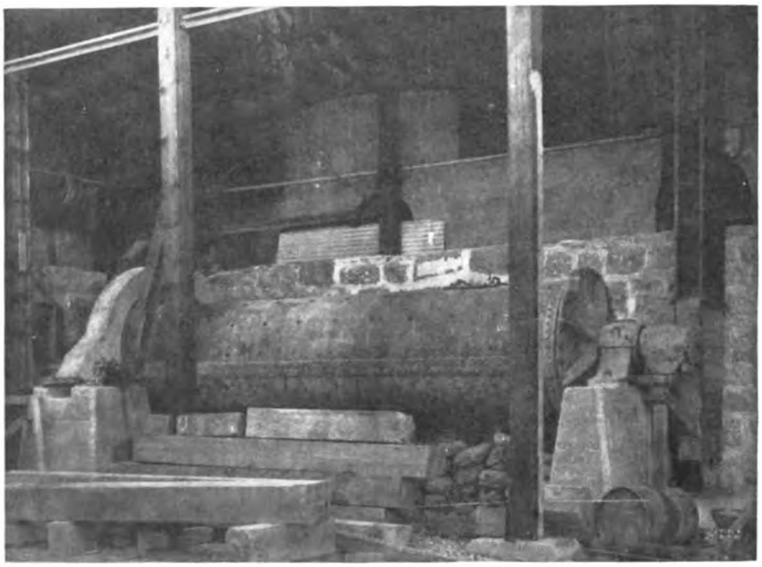
The material passes through the kiln, where it is subjected to a hot blast of gas, oil, or more usually, pulverized coal, the temperature of the gases varying from 1000° F. at the upper end where the raw material enters, to nearly 3000° F. at the lower end. The effect of this high temperature is to first expel all moisture from the material, and then to reduce the carbonates to oxides by driving off the carbon dioxide, just as is done in the manufacture of ordinary lime. In the hottest parts of the kiln, chemical reactions take place which result in the formation of silicates and aluminates of calcium, the essential constituents of cement. The product emerges from the kiln as cement clinker, which must be cooled before being handled. This is usually accomplished either in rotary coolers or in cooling towers, after which the clinker is ready for the last steps in the process—the final grinding and pulverizing.

This brief survey of the principal steps in the manufacture of cement, when supplemented by the statement that the grinding mills used require little attention, is enough to confirm the arguments previously advanced for the application of electric drive to this industry. The raw materials are cheap and easily obtained; the power required by the grinding mills is large, while the attendance is small; and the maximum efficiency can only be obtained when the entire plant is working to its full capacity continuously.

Roughly, of the power used in a dry process plant, 5 to 10 per cent. is expended in crushing the raw material, 30 to 35 per cent. in grinding and pulverizing on each side of the kilns, 3 per cent. in driving the kilns, and 15 to 20 per cent. in operating such auxiliary appliances as the coal grinders, blowers, dryers, coolers and conveyors, an astonishing number of the latter being required to handle the material in the various steps of manufacture. Thus, on the basis of the amount of power consumed, the grinding machines are by far the most important pieces of apparatus found in cement plants, and for this reason as well as others they are of the greatest interest from the standpoint of motor drive.

Mechanical Drive of Rotary Kiln

Perhaps the most distinctive grinding machine encountered in cement plants is the tube mill, which is a steel cylinder lined with silex or tough steel plates, and about half filled with flint or other smooth, hard stones. The mills are somewhat over twenty feet in length, with an internal diameter of about five feet, and are supported by stub shafts projecting from each end head. The shaft at one end of the mill is hollow, thus providing a path for conveying the material to the interior. The granulated raw material or the clinker (depending on whether the mill is being used on the raw or finishing end of the plant) is fed through the hollow shaft by means of a screw feed mechanism. The mill revolves at somewhat over twenty revolutions per minute, the exact rate depending on the diameter of the tube, and the pebbles, by rubbing against each other and against the shell grind the material to a fine powder which gradually works through the mill and discharges through the periphery of the head opposite the inlet.



Tube Mill

Tube mills revolve so slowly that it is necessary to use at least one gear reduction between the mills and their driving motors. They are usually driven by a pinion meshing with a gear fastened directly to one head of the mill. The countershaft, which usually operates at about 160 r.p.m., may be driven in various ways, such as by belting to a common line shaft which drives all the mills in the department, or by belting, gearing, or direct connecting to an individual motor.

Where a line shaft driven by a single motor is used, friction or jaw clutches are installed so that any mill can be disconnected at will. This system of drive represents the smallest possible initial investment for motors, but possesses the disadvantage of complication, the maintenance expenses of belts and clutches, and a somewhat lower efficiency than that given by the individual motor system. When individual motor drive is employed, the simplest and most efficient arrangement is obtained by connecting the motors directly to the countershaft of the mills by flexible couplings; but the relatively low motor speeds required make this somewhat more costly than the use of high speed motors with gears or belts. Its advantages, however, are apparently great enough to more than balance the extra investment, as some of the largest cement companies in the country are adopting it.

An important point in connection with tube mill motors is that they must exert more torque at starting than when running at normal speed. This is because the pebbles do not begin to roll until the mill has turned through a portion of a revolution, so that the center of gravity of the mass is at first raised somewhat above the position which it occupies while running. The fact that the bearings are dry and that the whole mass must be accelerated also help to make the starting conditions unusually severe.

Tube mills are primarily pulverizers and cannot work efficiently over a very wide range of fineness. The best results are obtained by reducing the material to a fairly fine powder, ten or twenty mesh, before feeding into the tube mills. For this preliminary grinding there are a number of different machines in use, ball mills being more frequently employed than any other one type. These mills are large steel cylinders, somewhat shorter in proportion to their diameter than tube mills, and partially filled with steel balls. The interior surface, instead of being smoothly lined as in tube mills, is made up of iron plates arranged in steps, so that as the cylinder revolves, the balls are continually falling against the shell and crushing the material. The material passes through holes in the plates into screens which are so arranged that all that is sufficiently fine passes through and falls into the hopper below, while that which is still too coarse is returned to the interior of the mill and reground. A ball mill differs in principle from a tube mill in that the grinding is done principally between the balls and the shell, while in the tube mill it takes place between the surfaces of all the pebbles in the mill.

Ball mills are driven in much the same manner as tube mills, and the same methods of applying motors are used, but the power required to grind a given amount of material is only about half that necessary with tube mills.

An interesting type of grinder which replaces both ball and tube mills in some plants, consists of a system of balls or rollers, grouped around a vertical shaft and driven at such high speed that they are thrown out by centrifugal force against the inside of a steel ring where the grinding takes place. Fans are arranged to blow the pulverized material against screens, and that which is sufficiently fine passes through and is carried out of the mill, while the coarser particles fall back and are further reduced.

The problem of driving this type of mill is sometimes solved by driving the vertical shaft by bevel gears, but more often by belting with quarter turn belts to a countershaft or motor. A number of installations have also been made with individual vertical shaft motors belted directly to the mills, thus avoiding the use of twisted belts. In selecting motors to drive this class of mills, care must again be taken to obtain machines adapted to heavy starting service, although for a different reason from that encountered in the case of tube and ball mills. Here it is the acceleration of the heavy moving parts of the mill and the tendency to clog when at rest that makes the starting conditions severe.

In addition to these three types of mills there are a number of other grinding appliances on the market that are used to a greater or lesser extent in combination with tube mills, the practice in this respect being by no means uniform. In some plants which use tube mills for pulverizing, ball mills are replaced by centrifugal or roller mills for the preliminary grinding; or by another type in which the material is granulated by rapidly revolving arms or hammers. Even in a single plant there is often considerable variation in the equipments of the various departments. One prominent cement company, for instance, uses ball mills for granulating its raw materials preparatory to pulverizing in tube mills, roller mills being used on the finishing end; while for pulverizing the coal for the kilns, machines of the centrifugal type are used.

Next in importance to the grinding mills, from the standpoint of power consumption, is the crushing plant. The equipment of this department does not offer such a wide variety of apparatus to choose from as that which confronts the engineer when selecting grinders and pulverizers, since practice is limited almost exclusively to the use of gyratory crushers for reducing rock and shale, and to rolls for coal. Gyratory crushers are also sometimes supplemented by roll crushers for the final reduction of the raw material, before it passes to the grinding mills.

A gyratory crusher consists essentially of an inverted frustum of a cone through which passes a heavy vertical shaft fitted with a conical crushing head. The shaft is so arranged that it is free to revolve around its own center at the top, while the lower end is driven by an eccentric and not only revolves on its own axis, but also has a planetary motion imparted to it. The material is fed into the top of the crusher and as it works its way down around the shaft, is gradually broken up between the shell and the gyrating crushing head, until it is fine enough to fall through into the discharge spout. Raw material is usually crushed in two different sizes of crushers, one large machine delivering its output to two or more smaller ones.

It is always advisable to belt crushers because of their liability to stall in case some foreign substance accidentally gets into the hopper of the machine, and although they are generally supplied with break pins or couplings to prevent damage from this cause, a belt that can slip off under too heavy an overload, gives an added protection to the motor which is well worth having. This, combined with the fact that all of the machines are usually operating at the same time, has made group drive in the crushing department rather more popular than the use of individual motors. The latter scheme, however, is used quite frequently, and when motors are selected for this work, it should be borne in mind that they may be called upon to exert at least their normal running torque when starting, if the crusher is full.

The connecting link between the raw and finishing ends of a cement plant is the kilns. In all modern plants, these are of the rotary type and are slightly inclined so that the material, after being fed into the upper end, gradually works through to the lower, the rate of travel depending on the speed at which the kiln is rotated. In order to secure the best results in the matter of efficiency and uniformity of product, it is usually considered necessary to have some means of varying the speed of the kilns, and it is this fact that makes them of especial interest from the motor standpoint, in spite of the comparatively small power required.

The necessary speed variation may be accomplished either by mechanical speed changing devices driven by constant speed motors or line shafts, or, as is more frequently the case, by the use of variable speed motors. The latter method offers no difficulties in direct current plants, but is not so satisfactory where only alternating current is available, as the use of induction motors with resistance inserted in their rotor circuits means quite an appreciable loss of power on any but the highest speeds. This objection has been overcome in some cases by the installation of a motor-generator set, and the operation of the kiln motors by direct current.

The range of speed variation specified by different cement manufacturers varies from 3½ to 1 down to 2 to 1; the latter being the one most commonly used, experience indicating that where larger ratio motors are installed the full available range is seldom, if ever, taken advantage of.

The extremely low rotary speed of kilns—from one half to two revolutions per minute—makes necessary the use of several gear reductions in order to give a fairly high speed at the countershaft. A set of bevel gears is usually included in the train, so that the plane of the driving pulley is parallel to the axis of the kiln. This arrangement minimizes the floor space taken up by belting, and also does away with the use of a twisted belt, which would be made necessary by the slope of the kiln if only spur gears were used.

Rotary dryers and coolers are long steel cylinders, somewhat similar in appearance to kilns, and, as their names imply, are used for drying the raw material before grinding, and for cooling the clinker after it comes from the kilns. The power consumed by them is small, however, and they are only required to operate at one speed, so that they are comparatively unimportant from the motor standpoint.

The auxiliary apparatus required in cement plants includes conveyors and elevators of various types; blowers for forcing the blast of coal dust into the kilns, and sometimes for use with the coolers; and automatic weighing and sampling devices. Each of these consumes but little power, and may be driven either by an individual motor or, in case the mills are group driven, from the most convenient line shaft.

The general operating conditions found in cement plants have a large bearing on the class of electrical apparatus installed. In many respects, few industries present such unfavorable conditions, but fortunately these can be easily coped with if only taken into consideration when an equipment is selected. Where cement manufacturers have had trouble with their electrical machinery in the past, it has usually been due to attempts to apply standard apparatus to special conditions.

The most apparent danger to both motors and their controlling appliances arises from the enormous amount of dust prevalent around a cement plant. This not only threatens the motor bearings, but also the commutators of direct current machines and the contact surfaces of switches and circuit breakers when these are freely exposed. As far as the bearings are concerned, effective protection can be given by fitting the motors with dust guards, which consist of metal washers backed by felt and attached to each end of the bearing housings; but the problem of keeping commutators in good condition is more serious, and while many large plants are now operating successfully with direct current, the tendency is so strongly toward the use of alternating current that the latter system will undoubtedly be selected for the great majority of future installations.

In the brief description of the principal machines used in manufacturing cement it was seen that practically all of them may demand at least full load torque when starting, and, unless friction clutches are installed, this is a factor which must always be considered when the driving motors are designed. This requirement is met by the use of compound wound fields with direct current motors, and occasionally by the use of high resistance armatures with squirrel cage induction motors. For very large induction motors it is better to use machines of that type in which resistance is inserted in the armature circuit while starting; but the horse-power above which this practice becomes advisable varies considerably, depending on the size of the generating station, and on the importance of maintaining a steady voltage. In cement plants the tendency is to use squirrel cage motors up to somewhat larger capacity than would ordinarily be recommended, because, where operating conditions are as severe and continuity of operation as important as in this industry, their simplicity and ruggedness more than counterbalance the better starting characteristics of the slip ring type of motor. Squirrel cage motors are usually started by means of starting compensators, but sometimes are thrown directly on the line without any device for reducing the starting current. With large motors this latter method can be used only at the expense of considerably disturbing the voltage of the plant for a few seconds, and should not be considered if other customers are using power from the same generating station.

Two hundred and fifty volt apparatus is usually found in direct current plants, but practice as regards both voltage and frequency has varied considerably in installations where alternating current has been adopted. Cement plants are relatively large power consumers, and considerations of economy in the distribution system make it advisable to use at least 440 and preferably 550 volt motors; and the latter, which is the highest of the so-called standard low voltages, is now generally recommended for new plants.

The frequency selected may, of course, depend on such factors as the possibility of tying-in with some existing generating system, or of selling power to neighboring plants or towns; but when the choice is not influenced by these considerations, a twenty-five cycle equipment is preferable. This departure from the usual practice in industrial plants, where the use of sixty or forty cycles has long been standard, is due more particularly to the frequent use of direct connected motors with tube and ball mills, as already described. These mills usually operate at from 150 to 180 r.p.m., and at such slow speeds the characteristics of 25 cycle motors are so much more superior to those of higher frequency machines that the use of the latter can hardly be considered.

Controlling appliances, as mentioned in a former paragraph, are liable to injury if their contact surfaces are freely exposed to the stone and cement dust; they should therefore be of extremely liberal proportions to prevent any overheating. Alternating systems are more fortunate than direct current ones in this respect; for in the oil switches which are customarily used with induction motors no parts that can be injured are exposed.

The class of apparatus to be regarded as the best possible for any industry must be that one which makes the best average showing in all the important points to be considered, since one system seldom excels in all respects. Considerations of first cost are more weighty in some cases than in others, and, as previously pointed out, the character of a new installation may sometimes be influenced, especially in the matter of frequency, by factors outside of the cement plant itself. Under these circumstances, and in an industry having so many different types of apparatus in successful operation, it is difficult to call any one type standard. However, from the standpoint of both experience and theoretical considerations, this term can be applied most nearly to the twenty-five cycle, 550 volt alternating current system with individual and preferably direct connected motors for the grinding mills. The higher efficiency and reliability obtained by its adoption will usually be sufficient to outweigh its slightly greater first cost.

THE MANUFACTURE OF IRON AND STEEL IN THE ELECTRIC FURNACE

By John A. Seede

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Although Sir William Siemens used the electric furnace nearly thirty years ago, in substantially one of its present forms, and succeeded in melting some twenty pounds of steel, it was only recently that the electric furnace ceased to be a laboratory apparatus and became of commercial value.

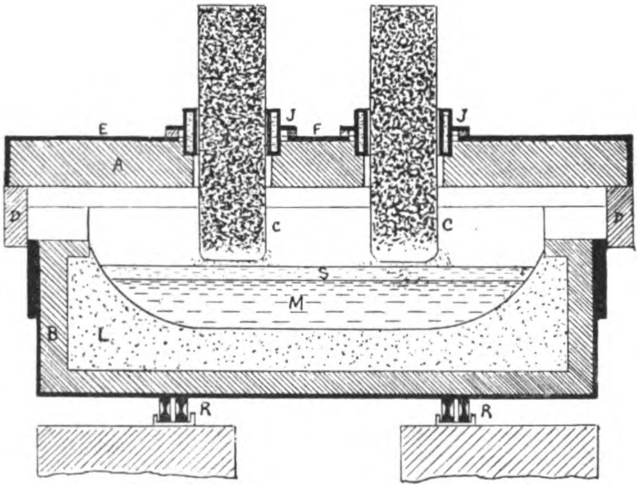


Fig. 1. Sectional Elevation of Heroult Furnace

Recent hydro-electric developments, with consequent cheapening of electric power, and splendid research work in the electro-metallurgy of iron and steel, have already led to such results as the partial elimination of the crucible furnace, a strong competition with the Bessemer converter and open hearth furnace, and even the bringing forward of a rival to the blast furnace.

All furnaces require a heat supply for their operation, and are alike in this respect; whether the heat is derived from gas, coal or other fuels—as in ordinary furnaces—or from electrical energy in the electric furnace.

Defining the efficiency of a furnace as that proportion of the heat value of the fuel (or electrical energy) that is actually utilized in heating the contents of the furnace, we have the following table of typical efficiencies for various furnaces:

Type of Furnace	Heat Efficiency Per cent.
Crucible steel furnaces, coke firing	2– 3
Reverberatory furnaces	10–15
Regenerative open hearth steel furnaces	20–30
Shaft furnaces (foundry cupolas, etc.)	30–50
Large electric furnaces	60–85

With the exception of induction varieties, all electric furnaces are of the arc or resistance type, or a combination of these two, and require some form of electrode, usually carbon or graphite. A brief description of typical furnaces, showing methods of supplying energy, may be of interest.

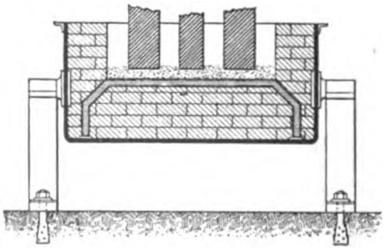


Fig. 2. Sectional Elevation of Girod Furnace

The Heroult furnace, shown in Fig. 1, is of the combined arc and resistance type, two or more electrodes being used, the current passing from one electrode down through the slag, across through the bath and up through the slag to the other electrode. As the resistance of the bath is small compared to the resistance of the slag and arc, most of the heat is generated at its surface, where the chemical action is going on between the slag and the metal.

The Girod furnace is similar to the Heroult furnace, with the exception that all the electrodes are connected to one side of the line, the water-cooled bottom being connected to the other side (see Fig. 2). In this furnace the current passes from the electrode through the slag to the bath, thence through the metal to the bottom and out.

Fig. 3 illustrates the Stassano furnace, which is of the pure arc type, the heat being obtained from an arc, drawn out between two or more carbon electrodes, which passes over but does not come in contact with the charge. This arc with less than 200 volts sometimes reaches a length of three feet or more.

The Colby, or Kjellin furnace, is of the pure induction type, without electrodes, the bath forming the short-circuited secondary winding of a transformer, and being heated by the enormous currents induced from the primary windings. A vertical section of this furnace is shown in Fig. 4.

The Roechling-Rodenhauser furnace (Fig. 5) is of the combined induction and resistance type, the greater part of the energy being furnished by induced currents, and a small part by a current passing between auxiliary electrodes placed at the slag line which come into action only when the furnace is hot. These electrodes are constructed of a heat insulator, which is also an insulator of electricity when cold but which becomes an electrical conductor when hot.

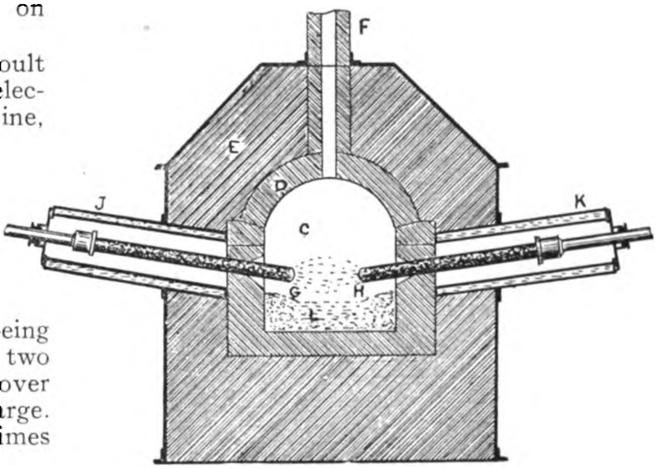


Fig. 3. Sectional Elevation of Stassano Furnace

The electric furnace has been used with success in refining steel, smelting pig iron, and in producing steel direct from the ore itself. In smelting pig iron, using high grade ore, from 1500 to 2000 kw. hours are required per ton of iron produced. In addition to the electrical energy, which supplies the heat of fusion, approximately 800 pounds of coke are required for the reduction of the ore. This is considerably less than the consumption of 2000 pounds required in the ordinary blast furnace (which, however, also supplies the heat at fusion), and the difference in favor of electric furnace increases as the quality of ore decreases.

Assuming a heat efficiency of 25 per cent. for fuel and 75 per cent. for electricity, then electricity is cheaper than coal when one ton of coal costs twice as much as one electrical horse power year. The energy required for smelting a ton of iron has varied in various experiments from 0.214 kw. years, to 0.250 kw. years.

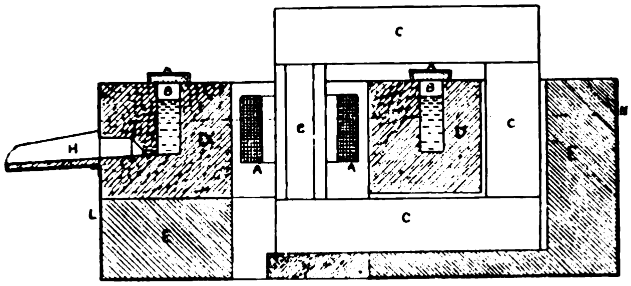


Fig. 4. Sectional Elevation of Kjellin Furnace

In a run of thirty-nine days, made by the Noble Electric Steel Company, Shasta County, California, the furnace operated for the first twenty-five days, producing 14 tons of iron with a power consumption of 0.435 kw. hours per ton; for the remaining fourteen days of operation the power input was increased, resulting in a production of 21 tons with a power consumption of 0.250 kw. hours per ton. This furnace is being extended to produce from 15 to 20 tons per day with an approximate input of 1500 kw.

The following table gives the composition of four bars of pig iron recently made in this furnace:

	1	2	3	4
Silicon	0.47%	0.51%	5.72%	5.70%
Sulphur	0.044	0.046	0.009	0.009
Phosphorus	0.051	0.041	0.053	0.053
Manganese	0.03	0.03	0.18	0.18
Total carbon	2.65	2.06	2.56	2.82
Combined carbon	....	....	0.20	0.15

As all four specimens were made in the same furnace, this illustrates how the use of the electric furnace permits the operator to vary the chemical composition of the product as desired. An estimated cost of operating a 1500 kw. furnace producing 15 tons per day, based on experience obtained in operating the 200 kw. furnace, would be as follows:

22.5 tons of ore at $1.75	$39.60
1.5 " " limestone at $1.00	1.50
1.5 " " andesite at $1.00	1.50
6 " " charcoal at $10.00	60.00
3 furnace firemen at $3.00	9.00
3 charging men at $2.50	7.50
3 men for mixing charge at $2.50	7.50
1 electrician at $3.00	3.00
Total	$204.60

This makes $13.64 per ton, to which $2.50 is added for incidentals, making a total cost of $16.14, which, with a freight rate of $2.50 per ton from this plant to San Francisco, gives a very reasonable margin of profit with a selling price of $28.00 per ton.

The ordinary blast furnace will not satisfactorily handle an ore having more than 0.15 per cent. sulphur, while very good pig iron has been produced in the electric furnace from ores containing ten times this percentage.

The formation of cyanides in a blast furnace is caused by the nitrogen of the blast in the presence of a basic slag, the nitrogen combining with the ferrite to form a nitride, the presence of which makes the iron brittle. From this it follows that nitrides may be formed in any air blast process, with attendant injurious effects on the mechanical properties of the product, and explains why certain steels with low sulphur and phosphorus contents show unaccountable brittleness. As the electric furnace uses no blast, nitrogen is eliminated, and the product is free from this fault.

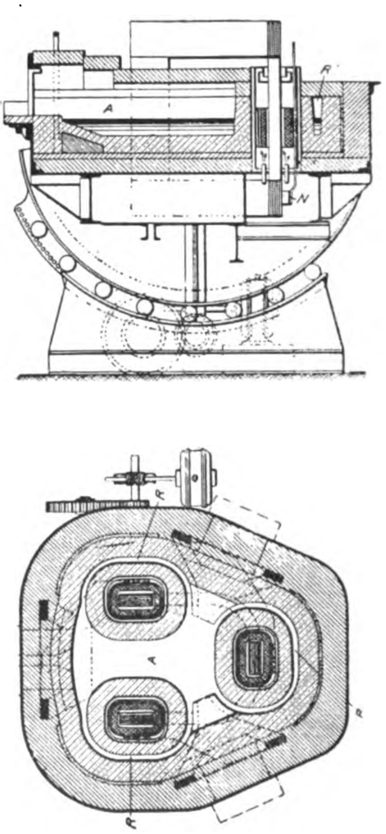


Fig. 5. Plan and Elevation of Roechling-Rodenhauser Furnace

For this same reason the gas issuing from the electric furnace will be much more suitable for combustion under boilers and in gas engines than that obtained from the blast furnace, as it contains many more heat units per pound than the latter. In addition to avoiding the formation of nitrides of iron, the smelting is done in a neutral atmosphere and almost absolute control of the chemical composition and temperature is obtained, a condition not to be found in any other furnace.

Where coke is not obtainable or only to be had at a prohibitive cost, charcoal made from waste ends and mill refuse may be substituted and serves as an admirable reducing agent. On account of the magnetic properties and electrical conductivity of magnetite, considerable difficulty was expected, due to increased inductance and difficulty in concentrating the current in sufficient density to produce the high temperatures necessary for fusion and reduction; no troubles directly traceable to these phenomena were experienced, however.

The amount of steel manufactured in the United States in 1906 was approximately:

Bessemer steel	12,000,000	tons
Open hearth steel	11,000,000	"
Crucible steel	118,000	"

Of this production, all of the crucible steel, and a considerable percentage of the open hearth and the Bessemer steels can be produced in the electric furnace; with a great saving in the case of the crucible steel, and a slight additional cost in the case of the other steels. For the crucible steels alone, this would require approximately 40,000 kw. of installation.

When we consider the tonnage of crucible steel referred to above, and that every ton requires from 20 to 25 crucibles, with consequent breakage, high labor charge and danger to workmen, it becomes evident that a tremendous saving can be effected by the use of a furnace having a capacity equal to the modern open hearth furnace and a product equal or superior to the best crucible steel. This becomes more evident when we realize that the number of men necessary to operate this furnace is only a slight percentage of that required to operate a crucible furnace, and that the charge itself may consist of a very poor quality of scrap in contrast with the carefully selected material necessary for charging the crucibles.

The tremendous expense and trouble required by the crucible furnace is evidenced by the fact that 1768 crucibles and the services of 490 men were required in the recent casting of an 80-ton ingot at the Krupp Works. This plant has a separate building for the manufacture of crucibles, with a capacity of 2000 to 3000 per day.

Without referring, at present, to the production of steel direct from ore, two methods of refining steel are used in the electric furnace, *viz:* cold charging and hot charging.

In cold charging, the scrap metal is placed in the furnace and melted down by the electrical energy; in which case approximately 550 to 600 kw. hours are required per ton of steel. The other method is to take the superoxidized metal from the Bessemer or open hearth furnace and refine it in the electric furnace; in which case approximately 250 kw. hours are required per ton of steel.

In a German plant a 250 h.p. electric furnace, having a capacity of 2200 pounds per charge and operated by three workmen, replaced a bank of 32 furnaces, each containing 6 crucibles with a capacity of 77 pounds each. With this furnace, using ordinary turnings and waste wrought iron costing approximately $13.00 per short ton, a fusion requires 3½ hours, with 1½ hours more to complete the refining process. The total cost per short ton of tool steel produced in this furnace is as follows:

Depreciation and interest	$1.09
Raw materials, including ferro alloy, etc.	15.13
Power, including heating between runs	9.75
Renewal of lining	2.59
Labor	2.16
Electrodes	.55
Water for cooling	.11
Total	$31.38

This type of furnace is not as efficient in power consumption as other furnaces, and even with cold charging, a power consumption of 900 kw. hours per ton is high; in addition the power rate was $70.00 per horse-power-year, making the cost of this item excessive. Under similar conditions; *viz.*, cold charging, tool steel has been produced with a consumption of 600 kw. hours per ton; with power rates at $30.00 per horse-power-year, this item becomes $2.75, or a saving of $7.00 per ton.

It has been proven that one of the most serious causes of brittleness in steel is the presence of manganese sulphide. This can only be removed by allowing the refined metal to stand a sufficient time for the sulphide to rise to the surface of the steel and be removed as slag, or by having the bath so free from sulphur that this compound cannot be formed except in minute quantities, and if a low sulphur ore is not available to start with, electric refining must be used.

The electric furnace is very effective in removing sulphur, and when once the sulphur is removed there is no danger of further contamination as in the open hearth furnace, where the charge may be contaminated by sulphur from impure gases. Even closed crucibles are not wholly proof against leakage, and this trouble may become serious with very impure gases.

As sulphur combines in the steel bath forming sulphides that are soluble in the steel and slag, the quantity of sulphides passing into the slag depends upon the temperature and basicity of the latter and its content of lime and manganous oxide. In the electric furnace practically any temperature may be attained, and consequently the basicity of the slag may be as high as desired.

As an example of the effect of removal of sulphur in the electric furnace, the analysis of 1000 successive charges gave the following results: 743 specimens had a sulphur content not greater than 0.010 per cent., while 958 specimens contained not more than 0.015 per cent. These results were not due to the use of especially pure raw materials, as the sulphur content of the charge varied from 0.035 per cent. to 0.500 per cent.

Steel direct from ore has been the ideal of the manufacturer, in view of the possibilities of increased production with consequent lowering of cost.

Steel has been produced direct from ore in the Stassano furnace with a consumption of 0.585 horse power years per ton of steel; Using ore with a sulphur and a phosphorus content of 0.120 and 0.150 per cent. respectively, the product, with a carbon content of 0.800 per cent. had .045 per cent. sulphur and 0.015 per cent. phosphorus. This steel had an ultimate breaking strength of 111,000 pounds per square inch with 13 per cent. elongation.

A process developed in this country and known as the Lash process, produces steel direct from ore, coke, and cast iron high in metalloids. The metalloids contained in the cast iron appear to act as reducing agents; from which fact we suppose that carbide of iron (as Fe_3 C) acts as a reducer. Besides these main constituents, lime or other fluxes may be added, sawdust to make the mixture porous, and some suitable binder when it is desired to briquette the mass.

The advantage of using this process is due to the greater cheapness of iron in the form of ore; so that, other things being equal, the greater the proportion of iron in the form of ore, the cheaper the product will be. In some experiments at Niagara Falls with this process, it was found that steel was produced with a consumption of 0.27 horse power years per ton, and even with this small power consumption an excessive amount of energy was used owing to the inexperience of the operators.

A three-ton furnace was used in these experiments, and about fifty tons of steel was obtained, in the form of ingots varying in weight from 200 to 425 pounds. The mixture used for the most part consisted of 60 per cent. iron ore, 23 per cent. cast iron, and the remainder of fluxes and carbon, the cast iron being in the form of borings or shotted pig iron.

In the preliminary experiments, as much as 15 per cent. of the iron was lost in the slag, this being reduced, however, in later runs to 6 per cent. and eventually even lower figures. While the power consumption of this process is less than half that required in the Stassano experiments, the electrode consumption is much greater; but in all probability the saving in power will overbalance the loss due to excessive electrode consumption.

That the electric furnace is gaining favor in steel refining is evident when we consider that there are 43 furnaces now in operation, having a combined capacity per charge of 251,000 pounds; and 36 in course of construction, of which 28 have a combined capacity per charge of 278,000 pounds, 8 as yet being undetermined. The largest furnace yet designed and in operation has a capacity per charge of 12½ tons, and a power input of 1200 kw. Most of these installations are in Europe, but in view of the rapidly awakening interest in this country we may expect great advances in the near future.

With pioneer electric furnaces, having outputs in the neighborhood of one ton per day, competing with the perfected modern blast furnace under the special conditions of cheap electric power and expensive metallurgical fuel, what may we not expect of the electric furnace when perfected by wide experience, and when the increased demand for fuel and the exhaustion of high grade ores shall have led to the inevitable handicapping of our present methods?

THE STORAGE BATTERY IN STEEL MILLS

By J. Lester Woodbridge
Chief Engineer, Electric Storage Battery Co.

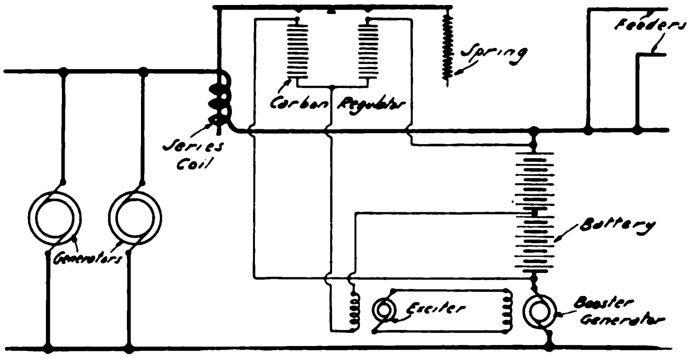


Fig. 1. Connections of Carbon Regulator

Possibly one of the most satisfactory methods of presenting the various engineering features involved in the application of storage batteries to the electric equipment of steel mills consists in a brief description of some of the important installations of this character, with an outline of their method of operation.

The first battery to be installed as an auxiliary to the electric power plant of a steel mill was that at the Carnegie Steel Co. at Youngstown, Ohio. The load at this plant, from readings taken prior to the installation of the battery, was of an exceedingly fluctuating character, varying from 1800 amperes to 4500 amperes at 260 volts. The swings from minimum to maximum were extremely rapid, nearly the entire range being frequently covered within a few seconds. A contemplated increase in the load promised to make the conditions still more severe, and called for an increase in plant capacity in the form of either generating machinery or storage battery. The battery was finally decided upon, and 126 cells of Chloride Accumulator, Type

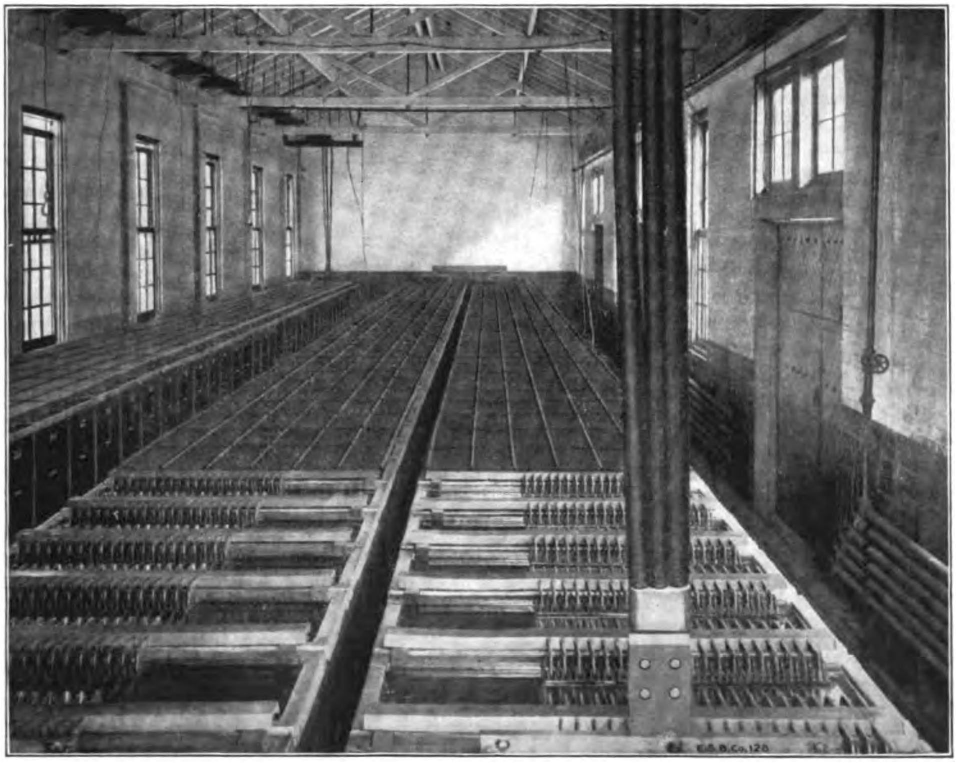


Fig. 2. Battery Room at the Carnegie Steel Company, Youngstown, Ohio
126 Cells Chloride Accumulator, 16,000 Amperes Capacity

41-G, with a capacity of 1600 amperes at the one hour rate, were installed in tanks of sufficient size to provide for an increase of 50 per cent. For the automatic control of the battery charge and discharge, a motor driven regulating booster was installed, its fields being controlled by an exciter, the armature of which is mounted on an extension of the booster shaft, and the fields of which are controlled in turn by a carbon regulator. This regulator consists of two series of piles of carbon discs arranged at opposite ends of a lever in such a way that motion of the lever produces pressure on one set of piles and relieves that on the other set, thus varying their relative resistances. The connections of this regulator are shown in the accompanying diagram, Fig. 1, the carbon piles being connected in series across the terminals of the battery while the field of the exciter is connected between the middle point of the battery and the middle point of the series of carbon piles. At one end of the lever which bears on the carbon piles is a spring, while at the other end is a solenoid which carries the total output of the generators. A small change in the generator output produces a variation in pressure on the carbon piles and a flow of current in one direction or the other through the exciter fields, thus causing the battery to charge or discharge. About a year after the battery was installed, the additional plates (for which space was provided in the tanks) were put in, increasing the battery capacity to 2400 amperes at the one hour rate.

Fig. 2 shows the battery room and Fig. 3 the regulating booster with its exciter.

The results of the operation of this battery in regulating the load fluctuations are shown in the load curve, Fig. 4, and in the indicator diagrams taken from one of the engine cylinders with and without the battery in operation, as shown in Figs. 5 and 6. It will be noted in each of these indicator diagrams that the pencil was held in contact with the paper for a period of five minutes. To one familiar with steam engineering it is hardly necessary to point out the difference in economical operation between the conditions represented by these two diagrams.

Another characteristic installation of a storage battery in connection with steel mill work is that of the Lukens Iron & Steel Works at Coatesville, Pa. As originally installed, this battery consisted of 120 cells of Type G-15 in Type G-21 tanks, operating on a 250 volt bus in conjunction with a booster fitted with carbon regulator control. In this case, also, the increase in capacity, for which provision was made in the size of the tanks, was installed soon after the battery went into service, the number of plates in each cell being in-

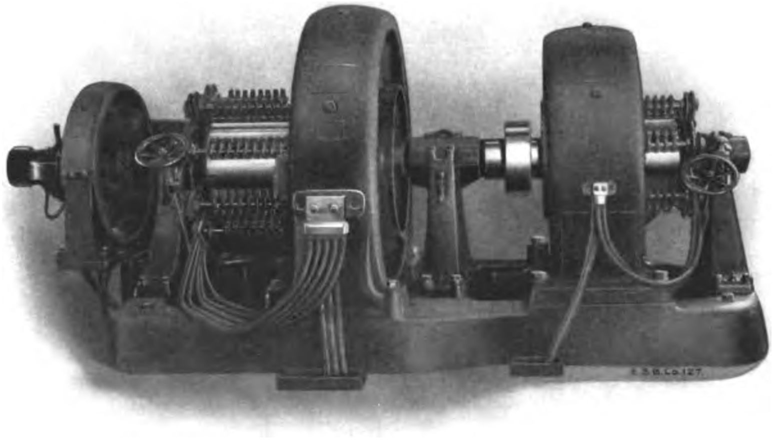


Fig. 3. Regulating Booster for Controlling Charge and Discharge of Batteries, shown in Fig. 2

creased from 15 to 21. The present capacity is therefore 800 amperes at the one hour rate. The accompanying load diagram, Fig. 7, shows the regulating results obtained, and the indicator cards reproduced in Figs. 8 to 11 inclusive show the results in the engine cylinders. As a further result of the operation of the battery, it is found that one-half of the generating machinery may be shut down and held as spare capacity, while without the battery the entire plant must be operated.

Among the more recent installations in this class of service is the battery installed at the Edgar Thompson Works in Pittsburg. This battery includes the largest cells installed to date for steel mill work and consists of 125 cells of Type R-85, in R-85 tanks. Each cell contains 85 plates of Type R, each plate measuring 18¾ by 18¾ in., the capacity of the battery being 5000 amperes at the one hour rate, or 10,000 amperes for 20 minutes, with an overload rating of 15,000 amperes momentarily. Aside from the large size of the cells in this plant, there are a number of novel and interesting features worthy of mention. The battery itself is located about 1000 ft. from the power house and in close proximity to the rolling mills, where the most severe fluctuations of load originate. In addition to relieving the generating machinery of these load fluctuations, the battery has also obviated the necessity of installing a considerable amount of transmission copper which would otherwise have been required.

Two boosters have been installed with this battery, each of which is designed to carry a momentary output of 15000 amperes, one machine acting as a spare for the other.

The boosters and their exciters are located at the battery, and two carbon regulators have been installed, one at the battery and the other at the power house, either of which may be used for the automatic control of the battery charge and discharge. Each carbon regulator is designed for distant control, and battery ammeters have been installed at both points so that the operation of the battery may be observed and controlled by the attendant at either point. Provision has been made for the installation of a second battery of the same size as the first, in which case a

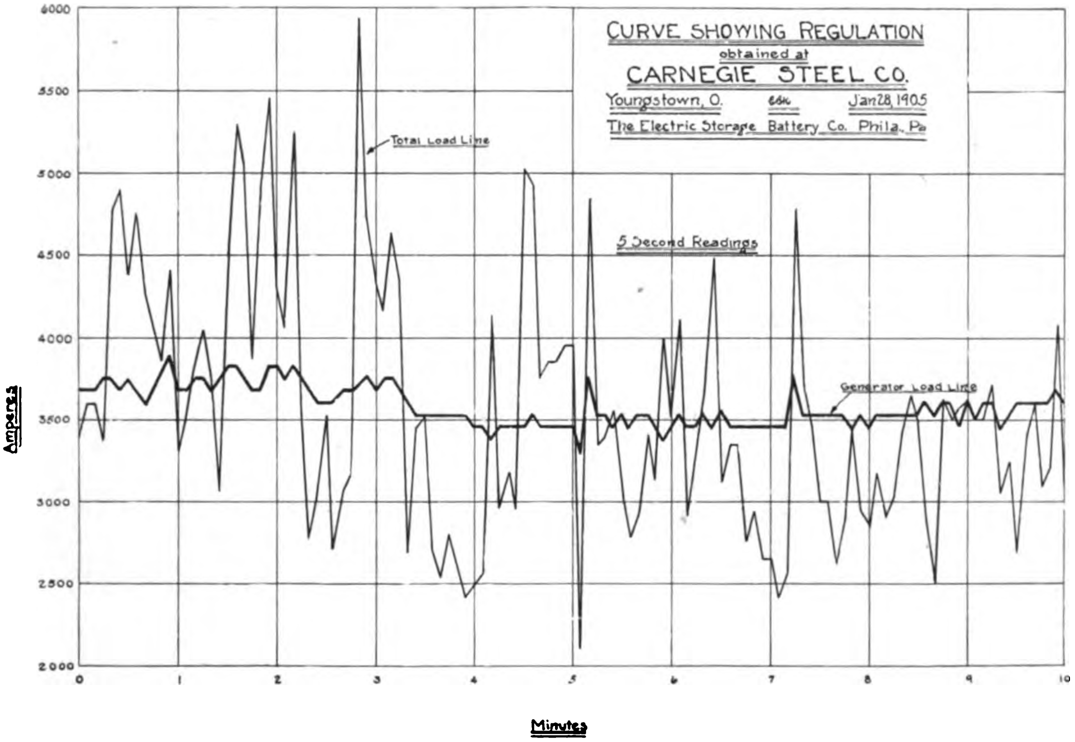
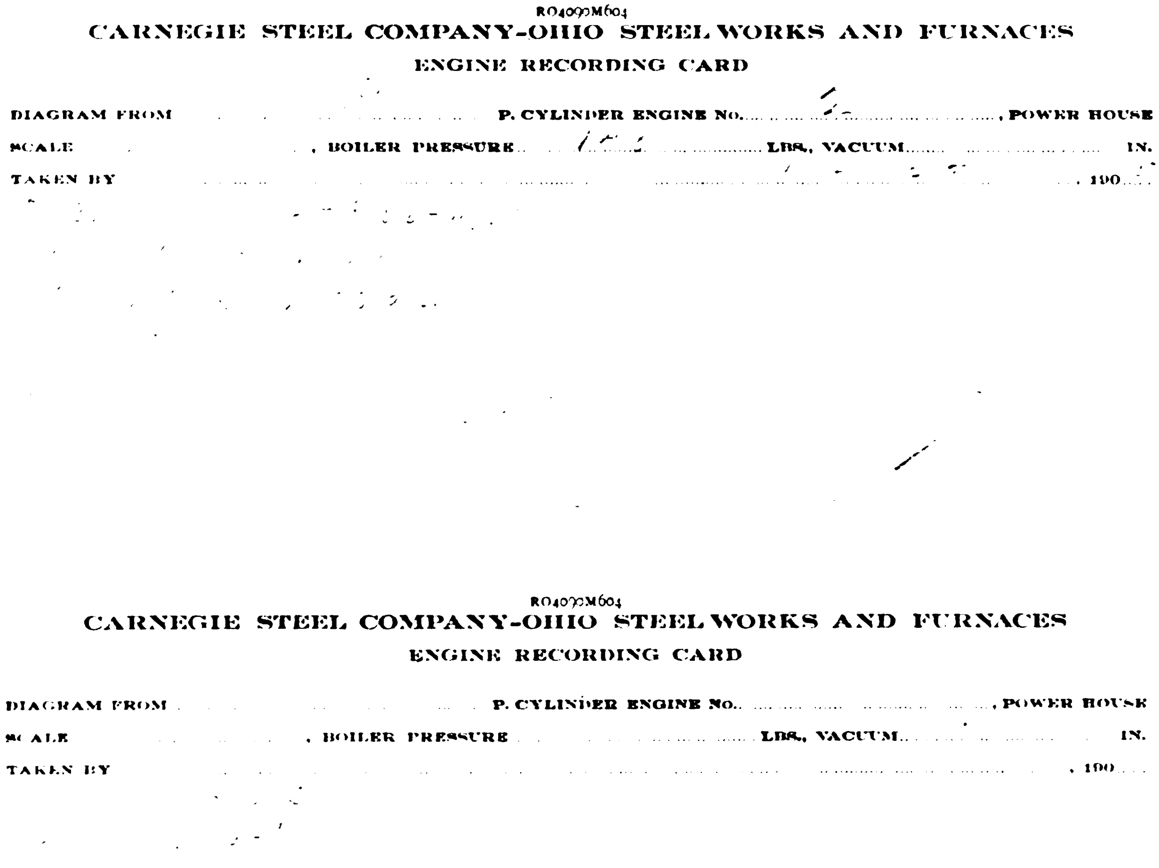


Fig. 4

third booster will be installed so as still to provide for one spare machine.

In order that the emergency service of this installation shall not be limited by the booster capacity, a special switching arrangement has been provided, consisting of an overload relay in the battery circuit which, when the battery current reaches a certain point, acts to kill the booster field and then short-circuit the booster armature, thus leaving the battery connected directly across the bus without the booster to handle any load that may be thrown on it. This arrangement was installed owing to the positive necessity of maintaining the current supply for operating the rolling mills under all conditions of service. On more than one occasion its automatic operation has prevented a complete shut down.

The load characteristics at this plant are peculiar, owing to the fact that, in addition to the severe momentary fluctuations, there occur wide changes in the average load from time to time. These features are shown in the load diagram, Fig 12, which forms a strik-



RO4090M604

CARNEGIE STEEL COMPANY-OHIO STEEL WORKS AND FURNACES

ENGINE RECORDING CARD

DIAGRAM FROM .... P. CYLINDER ENGINE NO. ...., POWER HOUSE

SCALE ...., BOILER PRESSURE .... LBS, VACUUM .... IN.

TAKEN BY .... 190...

RO4090M604

CARNEGIE STEEL COMPANY-OHIO STEEL WORKS AND FURNACES

ENGINE RECORDING CARD

DIAGRAM FROM .... P. CYLINDER ENGINE NO. ...., POWER HOUSE

SCALE ...., BOILER PRESSURE .... LBS, VACUUM .... IN.

TAKEN BY .... 190...

Figs. 5 and 6. Engine Diagrams. Upper Curve, Battery in Operation; Lower Curve, Battery Disconnected.

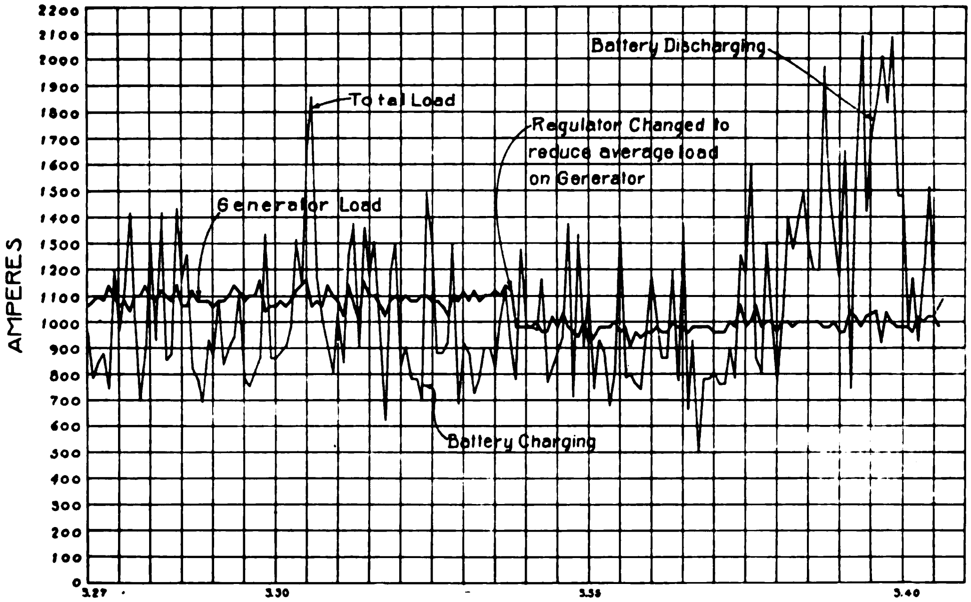
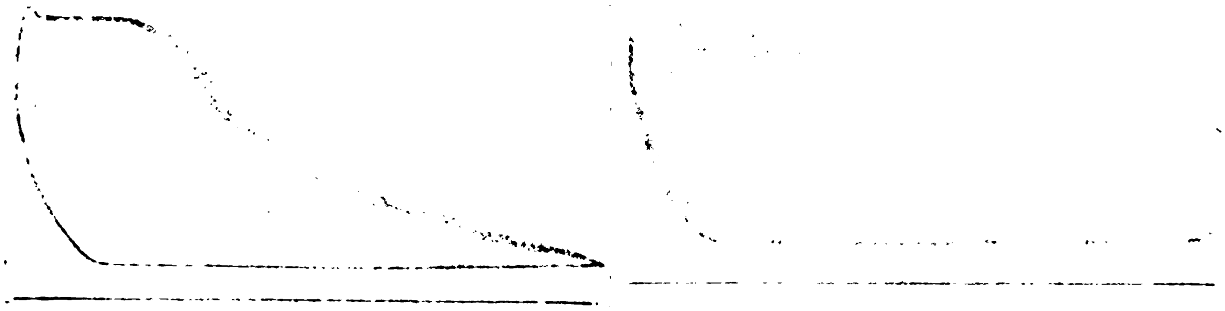


Fig. 7. Curve Showing Regulation Effected by Storage Battery Installed at the Lukens Iron and Steel Works, Coatesville, Pa.

ing contrast with the load curve of the Lukens plant, where the load fluctuations are rapid and severe but the average is fairly constant.

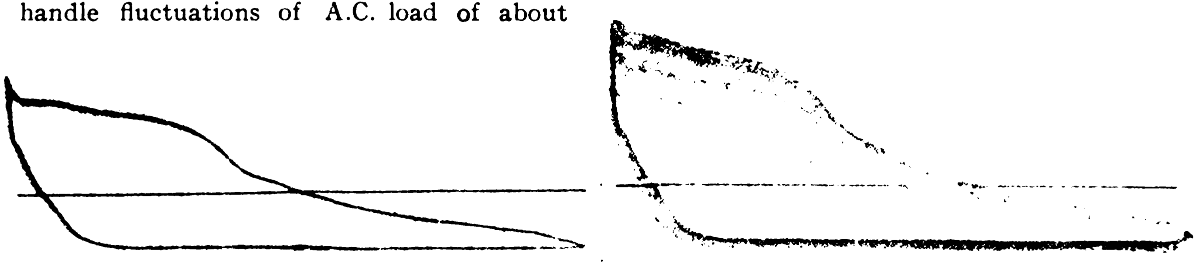
The most recent installation of a storage battery for steel plant work is that for the Indiana Steel Company at Gary, Ind. This installation, which will be put into operation within the next few weeks, consists of two series of cells, each series including 125 cells of Type R-73, the two series being operated in parallel with a total capacity of 8640 amperes at the hour rate. This battery is designed for controlling the fluctuations of load on both the A.C. and D.C. circuits. The D.C. fluctuations are handled through two motor driven boosters which may be operated in parallel and which are provided with carbon regulator control in accordance with standard practice; while the A.C. fluctuations are transferred to the battery through a split pole rotary converter, the voltage ratio of which is varied by varying the distribution of magnetic flux over the pole face. The A.C. voltage is thus held constant, while the D.C. voltage may be varied between the limits of 200 and 300 volts to cause the battery to charge from and discharge into the A.C. circuit. A second split pole converter identical with the first is to be installed in the near future; but for the present this will serve as a spare for the original



Battery in Operation **Battery Disconnected**

Figs. 8 and 9. Engine Diagrams, High Pressure Cylinder

converter, and may also be used for supplying a portion of the lagging current required by the heavy induction motors. Later, this second converter may be used to handle the output of two additional series of cells of the same capacity as those first installed, for which space has been provided. Each of these split pole converters is capable of delivering to the battery, as a true converter, 10,000 amperes momentarily at 300 volts, or of taking 14,000 amperes momentarily from the battery at 200 volts, operating inverted. The present battery installation can therefore handle fluctuations of A.C. load of about 3000 kw. on either side of the average, while the ultimate installation will be capable of handling fluctuations up to double this amount.



Battery in Operation

Battery Disconnected

Figs. 10 and 11. Engine Diagrams, Low Pressure Cylinder

The value of a storage battery auxiliary for emergency service, to insure continuity of power supply, will readily be appreciated when one considers the expense and delay incident to an interruption permitting the metal passing through the rolls to cool. An illustration of such service actually occurred at one of the plants of the Carnegie Steel Co. when a fire broke out at the power house, shutting off the normal current supply for operating the fire apparatus. The Superintendent states: "An electrically driven fire-pump, together with the electric light, both fed from the battery, probably saved our plant from destruction. The roof is about ninety feet from the yard level, and could not be reached by our regular water supply; but by speeding up the electric pump we were able to get enough pressure."

Another consideration which renders the regulating function of the storage battery of pronounced advantage in steel mills is the increasing use of gas engines operated by the furnace gases. The improvement in efficiency and reliability, the increase of capacity, and the saving in first cost effected by relieving this type of prime mover of the severe load fluctuations is even more marked than with steam engines.

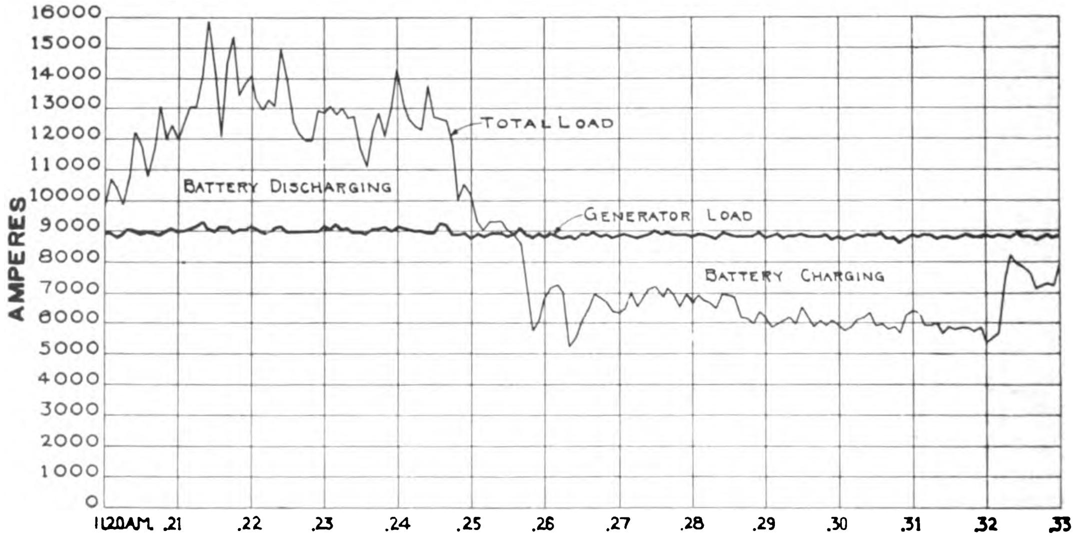


Fig. 12. Load Characteristic at Edgar Thompson Works, Pittsburg, Pa., and Regulation as Effected by Battery

THERMODYNAMICS

PART III

BY DR. CHAS. P. STEINMETZ

THERMODYNAMICS OF GASES

The fundamental equations of a gas were found to be—

1st $$p\,v = R\,T \qquad (1)$$

which applies to all gases. Where:

$R = \frac{r}{M} = \frac{848}{M}$, or 29.2 for air.

$r = 848$

M = molecular weight of the gas = 29 for air.

2nd The absolute equation $p\,v^a$ = constant. (2)

p = Absolute press. kg. per m^2.

v = Volume in m^3 per kg.

T = Absolute temp. = 273 + t.

a = 1.4 for air.

$$c = 1 - \frac{1}{a} = 0.285 \text{ for air.} \qquad (3)$$

From these equations the relations between pressure, volume and temperature can be calculated for any gas, such as air or the combustion of gas in a gas engine.

Adiabatic Energy

Let p_1 v_1 and T_1 be the pressure, volume and temperature under one condition, and p_2 v_2 T_2 the corresponding values after an adiabatic change, that is, a change involving no addition or subtraction of energy, we have then:

$$p_1\,v_1 = R\,T_1 \text{ and } p_2\,v_2 = R\,T_2$$

Thus:

$$\frac{p_1\,v_1}{p_2\,v_2} = \frac{T_1}{T_2} \text{ or } \frac{p_1}{p_2} = \frac{T_1\,v_2}{T_2\,v_1}$$

We have also: $p_1\,v_1^a$ = Const. (K) and $p_2 v_2^a$ = Constant (K).

Thus:

$$\frac{p_1 v_1^a}{p_2 v_2^a} = \frac{K}{K} = 1 \text{ or } \frac{p_1}{p_2} = \left(\frac{v_2}{v_1}\right)^a \qquad (4)$$

From these equations we get:

$$\left(\frac{v_2}{v_1}\right)^a = \frac{T_1\,v_2}{T_2\,v_1} \text{ or } \frac{T_1}{T_2} = \left(\frac{v_2}{v_1}\right)^{a-1}$$

and

$$\frac{T_1}{T_2} = \left(\frac{p_1}{p_2}\right)^{1-\frac{1}{a}} = \left(\frac{p_1}{p_2}\right)^c$$

where $c = 1 - \frac{1}{a} = .285$ for air.

The external or mechanical work done during the adiabatic change or the adiabatic energy

$$E = \int_{v_1}^{v_2} p\,dv$$

p and v are connected by equation $\frac{p_1}{p_2} = \left(\frac{v_2}{v_1}\right)^a$ as is shown in equation (4).

Thus:

$$\frac{v_2}{v_1} = \left(\frac{p_1}{p_2}\right)^{\frac{1}{a}}$$

hence

$$dv_2 = -\frac{1}{a} v_1 p_1^{\frac{1}{a}}\, p_2^{-\frac{1}{a}-1}\, dp_2$$

Applying this equation in the energy equation

$$E = \int p\,dv \qquad \text{we get:} \qquad (5)$$

$$E = -\frac{1}{a} v_1 p_1^{\frac{1}{a}} \int_{p_1}^{p_2} p \cdot p^{-\frac{1}{a}-1}\, dp$$

$$= -\frac{1}{a} v_1 p_1^{\frac{1}{a}} \int_{p_1}^{p_2} p^{-\frac{1}{a}}\, dp$$

$$= -\frac{1}{a} v_1 p_1^{\frac{1}{a}} \left[\frac{p_2^{1-\frac{1}{a}} - p_1^{1-\frac{1}{a}}}{1-\frac{1}{a}}\right]$$

$$= -\frac{v_1 p_1^{\frac{1}{a}}}{a-1}\left(p_2^c - p_1^c\right)$$

$$= \frac{v_1 p_1^{\frac{1}{a}}}{a-1}\left(p_1^c - p_2^c\right)$$

This equation can be further simplified, since—

$$p_1^{\frac{1}{a}} v_1 = p_2^{\frac{1}{a}} v_2$$

and $p_2 v_2 = R\,T_2$ or $v_2 = \frac{R\,T_2}{p_2}$

Thus:

$$p_1^{\frac{1}{a}} v_1 = \frac{p_2^{\frac{1}{a}} R\,T_2}{p_2} = R\,T_2\,p_2^{-\left(1-\frac{1}{a}\right)} = R\,T_2 p_2^{-c}$$

Substituting this in the energy equation we get:

$$E=\frac{R\ T_2\ p_2^{-c}}{a-1}(p_1^c-p_2^c)=\frac{R\ T_2}{a-1}\left[\left\{\frac{p_1}{p_2}\right\}^c-1\right]$$

we also have $\frac{T_1}{T_2}=\left\{\frac{p_1}{p_2}\right\}^c$

Therefore $E=\frac{\text{R}}{a-1}(T_1-T_2)$ (6)

For air this equation becomes $E=73\ (T_1-T_2)$ kg. m *From this it follows that the adiabatic energy depends only upon the temperatures.*

Isothermal Energy

This is the energy involved when a gas changes at constant temperature. We have, as before, external work $=\int pdv$, but $p_2v_2=p_1v_1$ and $dv_2=-\frac{p_1v_1}{p_2^2}dp_2$.

Therefore:

$$E=\int_{p_1}^{p_2}pdv=-p_1v_1\int_{p_1}^{p_2}\frac{p_2dp_2}{p_2^2}=-p_1v_1\int_{p_1}^{p_2}\frac{dp_2}{p_2}$$

$$\text{or } E=-p_1v_1\int_{p_1}^{p_2}\frac{dp}{p}=-p_1v_1\ (lg_\varepsilon\ p_2-lg_\varepsilon\ p_1)$$

$$\text{or } E=R\ T_1\ lg_\varepsilon\left[\frac{p_1}{p_2}\right] \qquad (7)$$

This equation can obviously also be written as:

$$E=R\ T_1\ lg_\varepsilon\left[\frac{v_2}{v_1}\right]$$

Isobaric Change

That is, change at constant pressure. In this case the work done is evidently—

$$E=\int_{v_1}^{v_2}pdv=p\int_{v_1}^{v_2}dv \text{ (since } p \text{ is constant)}$$

$$=p\ (v_2-v_1)$$

or since $p_1v_1=RT_1$

and $p_2v_2=RT_2$ and $p_1=p_2$

we get: $v_2-v_1=\frac{R}{p}(T_2-T_1)$

Thus, $E=R\ (T_2-T_1)$ (8)

Heat Cycles

In a gas engine work is done by impressing heat on the air and thereby changing its *pv*. The air expands and does mechanical work, and at the same time its temperature falls. Heat energy is abstracted and the quantity of air is brought back to its original condition. The time of heat supply is usually called its admission period, the time of heat abstraction its exhaust period.

Obviously this change of condition of the gas can take place in an infinite number of ways, of special interest are, however, the following:

First: *Constant temperature during admission and exhaust.*

Thus $T_1=T_2$

and $T_3=T_4$ *Carnot's Cycle.*

Such energy cycle consists of two isothermal curves 1–2 and 3–4 and two adiabatic curves 2–3 and 4–1 (See Fig. 1).

The mechanical work done is represented by the area 1–2–3–4, it is $E_{1-2}+E_{2-3}+E_{3-4}+E_{4-1}$.

Referring to equation (7) covering work during isothermal expansion:

$$E_{1-2}=R\ T_1\ lg_\varepsilon\frac{v_2}{v_1}$$

and $E_{3-4}=R\ T_3\ lg_\varepsilon\frac{v_4}{v_3}=-R\ T_3\ lg_\varepsilon\frac{v_3}{v_4}$

The work done during the adiabatic expansion is found from equation (6).

$$E_{2-3}=\frac{R}{a-1}(T_2-T_3)$$

and $E_{4-1}=\frac{R}{a-1}(T_4-T_1)=-\frac{R}{a-1}(T_1-T_4)$

Thus the total mechanical work is:

$$R\left[T_1\ lg_\varepsilon\frac{v_2}{v_1}-T_3\ lg_\varepsilon\frac{v_3}{v_1}+\frac{T_2-T_3-T_1+T_4}{a-1}\right]$$

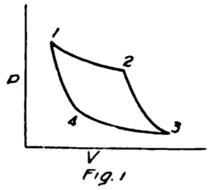


Fig. 1

Since, however, $T_1=T_2$ and $T_3=T_4$ we get:

$$E=R\left[T_1\ lg_\varepsilon\frac{v_2}{v_1}-T_3\ lg_\varepsilon\frac{v_3}{v_4}\right]$$

Referring now to equation (4)

We have $\frac{v_2}{v_1}=\left[\frac{T_1}{T_2}\right]^{\frac{1}{a-1}}$ and $\frac{v_3}{v_4}=\left[\frac{T_4}{T_3}\right]^{\frac{1}{a-1}}$

and since $T_1 = T_2$ and $T_4 = T_3$ we get $\frac{v_2}{v_1} = \frac{v_3}{v_4}$

$$\text{Thus } E = R\ (T_1 - T_3)\ lg_\varepsilon \frac{v_2}{v^1} \qquad (9)$$

which can also be written as:

$$E = R\ (T_1 - T_3)\ lg_\varepsilon \frac{p_1}{p_2} \qquad (9)$$

The input is readily determined since at point 2 the internal energy is the same as at 1, therefore, the energy input represents the work done.

The energy input is $E = RT_1\ lg_\varepsilon \frac{v_2}{v_1}$, thus the efficiency—

$$\phi = \frac{R\ (T_1 - T_3)\ lg_\varepsilon \frac{v_2}{v_1}}{RT_1\ lg_\varepsilon \frac{v_2}{v_1}} = \frac{T_1 - T_3}{T_1}$$

Assuming as an instance that the higher temperature is 800° C., thus $T_1 = 800 + 273 = 1073$, and the lower temperature 30° C., or $T_3 = 303°$.

$$\text{Thus } \phi = \frac{1073 - 303}{1073} = 0.717$$

This is of course a very high efficiency for a heat engine, but the pressures involved are so great that such a high efficiency cannot be obtained practically. To calculate these pressures, assume the lower pressure slightly above the atmospheric, or $p_3 = 1.2 \times 10^4$ kg. per m^2. We have: $p_3 v_3 = R\ T_3$. Thus

$$v_3 = \frac{29.2 \times 303}{1.2 \times 104} = 0.735.$$

We also have (4):

$$\frac{p_2}{p_3} = \left[\frac{T_2}{T_3}\right]^{\frac{1}{c}} = \left[\frac{1073}{303}\right]^{3.5} = 83.4$$

Thus: $p_2 = 1.2 \times 83.4 \times 10^4 = 100 \times 10^4$, that is, one hundred atmospheres or 1470 lbs. per sq. in., a value altogether too high to be practical.

It is of interest to calculate the maximum practical efficiency of the Carnot cycle. The high pressure limit p_1 will be assumed as 25 atmospheres, the low pressure 1.2 atmospheres. 1 kg. of air is considered, therefore, the volume at 1.2 atmos. pressure is

$$v_3 = \frac{29.2 \times 303}{1.2 \times 10^4} = 0.737.$$

The area enclosed or useful work depends upon the assumption of the intermediate temperatures or pressures, p_2, T_2, p_4, T_4. The work is a maximum when $\frac{dE}{dT_2} = 0$, or $\frac{dE}{dp_2} = 0$.

Solving this equation we find the best values of p_2 and T_2 are: $p_2 = 6.52$ and $T_2 = 491$. Thus T_1 the initial temperature is 491° abs. also.

The volume and pressure at the end of the exhaust periods are found as follows:

$$\frac{T_1}{T_4}\left[\frac{p_1}{p_4}\right]^{.285} \text{ or } \left[\frac{T_1}{T_4}\right]^{3.5} = \frac{p_1}{p_4}$$

Thus $\left[\frac{491}{303}\right]^{3.5} = \frac{25}{p_4}$ or $p_4 = 4.63$ atmospheres.

We have also $p_4 v_4 = RT_4$, thus $_4$

$$v_4 = \frac{29.2 \times 303}{4.63 \times 10^4} = 0.191$$

The work done is obtained from equation (9). $E = 29.2\ (491 - 303)\ lg_\varepsilon \frac{25}{6.52} = 7380$ kg m

The thermal efficiency $\phi = \frac{T_1 - T_3}{T_1} = \frac{491 - 303}{491} = 0.383$.

It is seen that this efficiency is quite low. The reason is obviously that the maximum temperature is too low, yet a higher temperature means a higher initial pressure, which is not practical.

A better cycle is, therefore, to increase the temperature during the admission period, keeping the pressures constant, that is to make $p_2 = p_1$. More output can also be obtained and the mechanical efficiency improved, if instead of isothermal compression, the compression is done at constant pressure. In other words, instead of reducing the volume from v_3 to v_4 it should be kept constant by throwing away gas corresponding to the difference in volume $v_3 - v_4$, practically the engine exhaust, into the atmosphere and then drawing in a new charge of air.

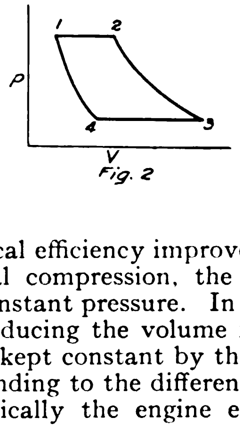


Fig. 2

This leads to the second typical cycle, *viz*:

2nd. *Constant Pressure During Admission and Exhaust.*

Then $p_1 = p_2$, $p_3 = p_4$. This is the cycle of the gas turbine (See Fig. 2).

$$\begin{aligned} p_3 &= p_4 = 1.2 \times 10^4 \\ T_4 &= 303 \\ v_4 &= .737 \end{aligned}$$

$$E = E_{1-2} + E_{2-3} + E_{3-4} + E_{4-1}$$

$$E_{1-2} = R\ (T_2 - T_1) \quad \text{(Isobaric)}$$

$$E_{3-4} = R\ (T_4 - T_3) \quad \text{(Isobaric)}$$

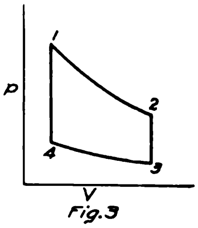


Fig. 3

$$E_{2-3} = \frac{R}{a-1}\ (T_2 - T_3) \quad \text{(Adiabatic)}$$

$$E_{4-1} = \frac{R}{a-1}\ (T_4 - T_1) \quad \text{(Adiabatic)}$$

$$\text{and } E = \frac{R}{C} \left\{ T_2 - T_1 - (T_3 - T_4) \right\} \qquad (10)$$

The following relations exist between the pressures and temperatures.

$$\frac{p_2}{p_3} = \left(\frac{T_2}{T_3} \right)^{3.5} \text{ and } \frac{p_1}{p_4} = \left(\frac{T_1}{T_4} \right)^{3.5}$$

Since $p_1 = p_2$ and $p_3 = p_4$, we get $\frac{T_1}{T_4} = \frac{T_2}{T_3}$

or $T_1\ T_3 = T_2 T_4$ or $T_1 = T_2 \frac{T_4}{T_3}$

In this equation $T_2 = 1073°$ and $T_4 = 303°$.

Thus $T_1 = \frac{325{,}000}{T_3}$

Substituting these values in equation 10 we get:

$$E = \frac{R}{C} \left\{ 1073 - \frac{325{,}000}{T_3} - T_3 + 303 \right\}$$

Differentiating T_3 to get the maximum value of E we get:

$T^2_3 = 325{,}000$ or $T_3 = 570$, and $T_1 = 570$.

The work done is—

$$E = \frac{29.2}{.285}\ [1073 - 570 - 570 + 303] = 24{,}200 \text{ kg m}$$

$$\text{and the efficiency is } \phi = \frac{1073 - 303}{1073} = 0.717$$

The volume v_3 is, however, 1.39, therefore, the work referred to a volume of .737 is only 12800 kg m.

3rd: *Constant admission volume v_1 and constant exhaust volume v_3, or $v_4 = v_1$ and $v_2 = v_3$* (See Fig. 3).

This cycle leads either to a high pressure or a small output and is therefore of little interest.

$$E = E_{1-2} + E_{2-3} + E_{3-4} + E_{4-1}$$

Since the volume does not change between 2 and 3 and between 4 and 1 the work is—

$$E = E_{1-2} + E_{3-4}$$

From 1 to 2 and 3 to 4 the change is adiabatic, thus:

$$E_{1-2} = \frac{R}{a-1} \left\{ (T_1 - T_2) + (T_3 - T_4) \right\}$$

It is readily found that the maximum work is 17,200 kg m and the thermal efficiency, as before, 71.7 per cent.

The fourth case is a combination of the two previous and corresponds fairly accurately to the cycle of the gas engine.

4th. *Constant Admission Pressure, Constant Exhaust Volume* (See Fig. 4).

$$\begin{aligned} p_1 &= p_2 \\ v_3 &= v_4 \end{aligned}$$

During admission $p =$ constant.

During the adiabatic expansion $p\ v^a =$ constant or $p^{\frac{1}{a}} v =$ constant. Between $3-4$ the volume v is constant and during the adiabatic expansion $4-1$, $p^{\frac{1}{a}} v =$ constant.

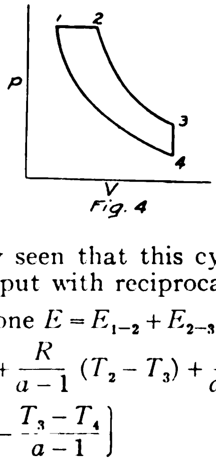


Fig. 4

It is readily seen that this cycle gives the maximum output with reciprocating engines.

The work done $E = E_{1-2} + E_{2-3} + E_{4-1}$

$$= R\ (T_2 - T_1) + \frac{R}{a-1}\ (T_2 - T_3) + \frac{R}{a-1}\ (T_4 - T_1)$$

$$= R \left\{ \frac{T_2 - T_1}{C} - \frac{T_3 - T_4}{a-1} \right\}$$

In this cycle $p_4 = 1.2 \times 10^4$
$T_4 = 303$
and $T_2 = 1073$

It is easily proven that maximum work is obtained when $T_1 = 632$ and $T_3 = 632$.

E then becomes 24150 kg m

and the thermal efficiency 71.7 per cent. as before.

We see from this that, barring the first cycle, Carnot's cycle, the thermal efficiency is the same throughout. The mechanical efficiency is, however, different, since the amount of work for a given cylinder dimension varies considerably.

Assume, for instance, that in the last case, when the work is a maximum, the mechanical efficiency is 90 per cent. The mechanical loss will be equal in all the other cycles, and the various efficiencies work out as follows:

	Output	Loss	Net Output	M. Eff.	Th. Eff.	Tot. Eff.
1st Cycle	7380	2415	4965	67	38.3	25.6
2nd "	12800	2415	10385	81.5	71.7	58.3
3rd "	17200	2415	14785	86	71.7	61.5
4th "	24150	2415	21735	90	71.7	64.4

(To be Continued)

AUTOMATIC CONTROL APPARATUS IN CONNECTION WITH THE ELECTRICAL OPERATION OF STEEL MILLS

By H. E. White

The conditions under which electrical apparatus must operate in a steel mill are such that only the most substantial and effective controlling devices can long endure. Under such conditions, certain inherent advantages of control by magnetic switches or contactors have caused them to become the recognized standard for this class of work. It is the purpose of this article to point out these inherent advantages in detail and to show how they may be applied to steel mills and other similar service.

It may be taken for granted that electrical engineers are familiar with the general design of controlling apparatus, but to many it may not have occurred to investigate the cause of the great variety of control devices and to seek the reason why contactor control is so rapidly superseding other types of control for heavy service.

The most important thing bearing on the subject is the nature of the phenomena which accompany the opening of electric currents of varying magnitude and voltage. Early investigators were fascinated by the novel effects which they witnessed when they succeeded in getting currents powerful enough to fuse metal and produce arcs, but the modern engineer seeks to mitigate by every means at his command these effects in switching and controlling devices. In detail, the effects on the contact-making parts fall under two heads. The first of these is flame-arcing, which takes place between the contacts while separated by appreciable distances. The effect of flame-arcing is, contrary to general opinion, less objectionable than the other effect, which is the fusing of the contacts due to imperfect contact while opening or closing. The effect of flame-arcing is mostly felt on the adjacent insulation; its effect on the con-

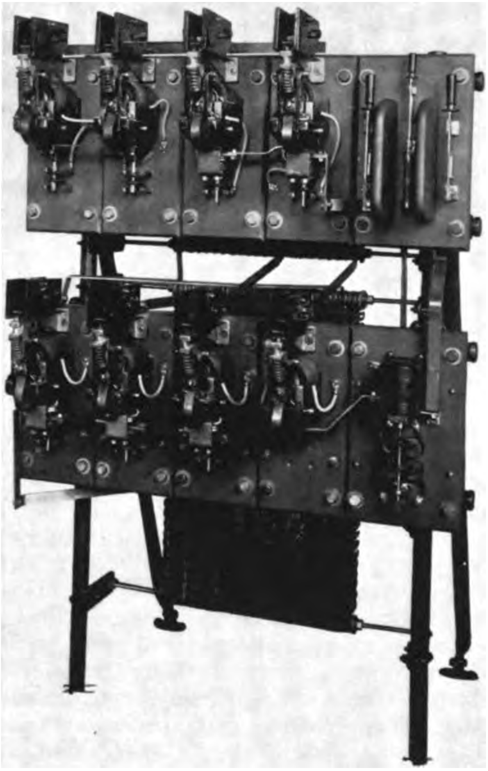


Fig. 1. Automatic Control Panel for 125 H.P., D.C. Motor with Separate Relays for each Point

tacts is, however, not so serious, for the reason that the amount of metal volatilized even by a seemingly voluminous arc is very small. The magnetic blowout, moreover, is a very effective means of reducing the duration of the arc to a very small interval of time with a corresponding reduction in the amount of metal volatilized. It can be applied with equal success to either alternating or direct current. Unfortunately, however, the magnetic blowout has no effect whatever on the fusing action at the point of contact. Such being the case, recourse must be had to a quick opening and closing of the contacts, either alone or in combination with the use of refractory material for the contacts if the currents to be closed are very high. Carbon is, of course, the only commercially available substance of the proper nature.

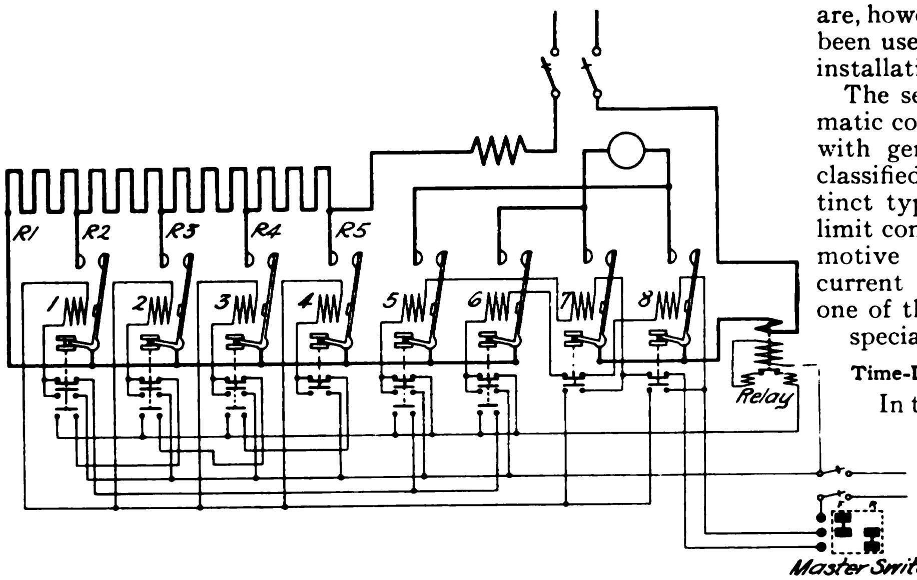


Fig. 2. Current Limit Control with Single Relay

Bearing these facts in mind, it can then be seen that the electro-magnetic switch has all the necessary elements for success; for it can be provided with magnetic blowout, and its actuating solenoids and compression springs so apportioned that it will open and close with a quick, snappy action. It only remains to so design the contactor that its durability will be suitable to the intended service, and so that its accessibility for inspection and needed repairs will commend it to its users. In the course of development of contactors, two types will undoubtedly persist, both having the above features; one being intended for street railway operation and for mounting beneath a horizontal surface, such as the car floor; the other being designed for support from a vertical surface. By referring to Figs. 6 and 8, contactors of the latter type, specially suitable for use in steel mills, will be seen.

Since the current required to actuate these contactors is small, they may be operated by a suitable master switch for the purpose of controlling motors from any distance. In some of the very earliest installations, equipments without any automatic features were furnished. The advantages of automatic current limit control are, however, such that it has been used in all of the recent installations.

The several types of automatic control that have met with general favor may be classified under several distinct types, as follows: time-limit control; counter electromotive force control; and current limit control. Each one of these systems has its special advantage.

Time-Limit Control

In time-limit control the contactors are arranged to close in sequence, either by means of a master controller which is provided with a dashpot or some other retarding device, or, if the accelerating period is very short, by arranging each contactor with auxiliary contacts which close the operating circuit of the next contactor. The self induction of the operating coils and the mechanical inertia are such that each contactor will take an appreciable time to close. This method of control is applicable only where a very light load is to be accelerated. Time-limit control has the advantage that, regardless of the load on the motor, the control will continue cutting out resistance so that the load will be started, unless it exceeds the power of the motor and the calibration value of the circuit breaker used.

Time-limit control is well adapted to operations that are of a uniform cyclic nature, with unvarying loads. Whenever it is used, however, for an exceptionally heavy load, the motor will be greatly overloaded, while if used with a light load, time will be lost in acceleration. Most of the master controllers arranged for time-limit control are dependent upon dashpots, or escapements more liable to derangement from slight causes than are master controllers for either e.m.f. or current unit control. Also, greater muscular effort is usually required on the part of the operator of the master controller.

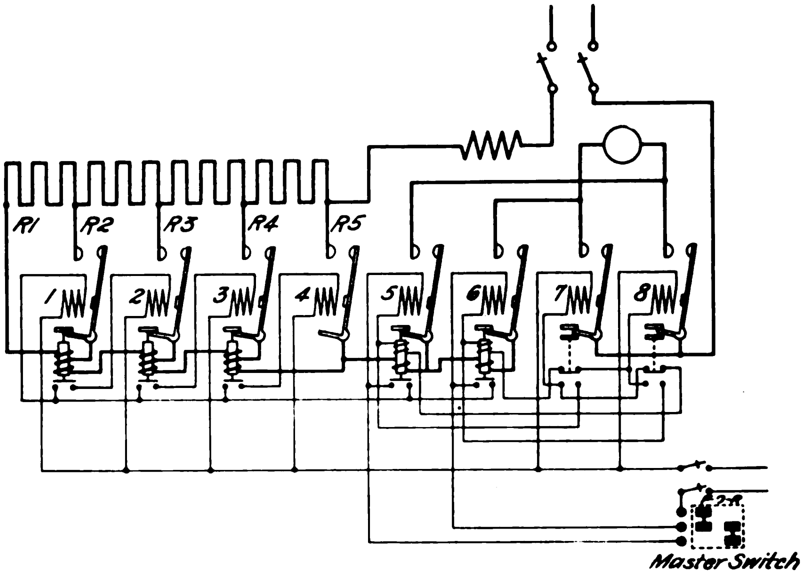


Fig. 3. Current Limit Control with Separate Relay

Counter E.M.F. Control

The contactors may be made to control the motor by arranging them so that each successive contactor requires a higher voltage to operate it than the one preceding. The contactors are then connected in multiple with the armature of the motor, and, as the motor comes up to speed, its counter e.m.f. meanwhile increasing, the contactors close in their proper sequence. This is the simplest automatic control system possible, dependent upon the motor load. It is, however, subject to certain limitations, among which is the effect of abnormal voltage on the line. First, if the line voltage is high, the contactors will close prematurely, and if it is low, some of them will not close at all. Second, the contactor coils, in order to operate satisfactorily, have to be designed with a very liberal amount of copper in their windings.

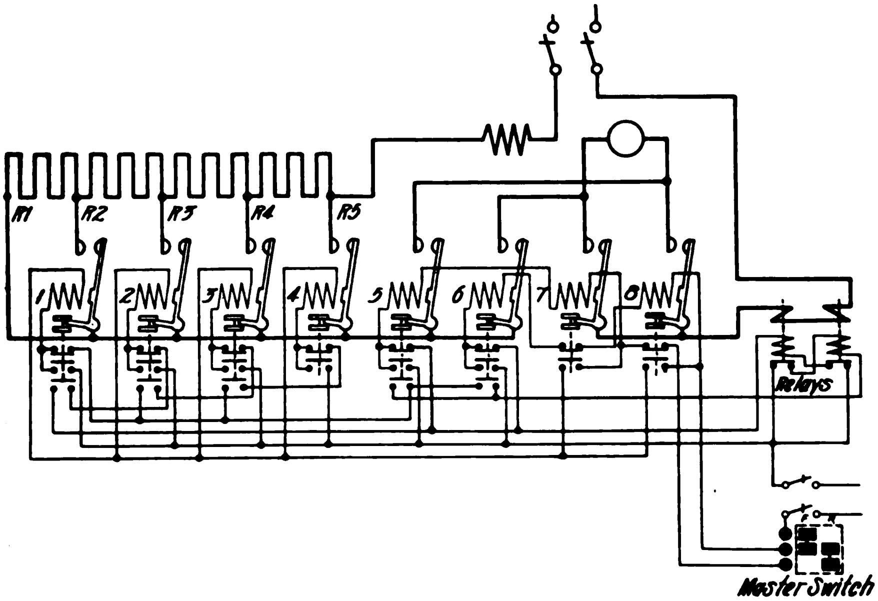


Fig. 4. Current Limit Control with Double Relay

Third, the system is not well suited to series motors without important modifications, for the reason that the counter e.m.f. of a series motor is a function of the current as well as of the speed. The action of counter e.m.f. control is liable to be interfered with by changes in the temperature of the contactor operating coils.

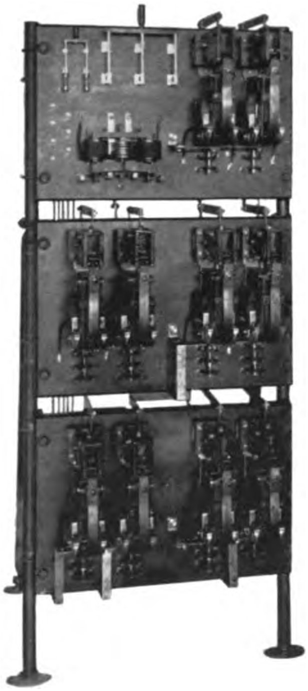


Fig. 5. Automatic Control Panel for 350 H.P. Induction Motor

Current Limit Control

This is the only system which is perfectly free from the defects of time-limit control and counter electric motor force control. It is the system unreservedly recommended for mill service. At the present time, its development is following along two distinct lines. In one, the circuits by which the contactors are caused to operate are controlled by auxiliary contacts on the contactors themselves. This system is the preferable one where the motors to be controlled are subjected to frequent starting, stopping, and reversing under load. In the other type, when used for regulating large motors driving continuously, where the number of contactors is relatively large and where automatic regulation both for accelerating and decelerating under load is required, as in the case of the 2000 and 6000 h.p. induction motors at Gary described elsewhere, a pilot-motor operated device possesses important advantages. The pilot motor or equivalent device serves the purpose of actuating the contacts which connect the contactors into circuit, the pilot motor being under the control of the operator, and also under the control of overload relays.

In the case of interlock type of current limit control, the General Electric Company is now furnishing two distinct systems, in one of which a single relay or pair of relays control the action of the contactors, while in the other a separate relay is used for every point. In the first system the current limit value in amperes must be the same on all of the contactors; in the second, the contactors may be separately set to operate at any desired current, so that every possible condition may be met. The second system has the very important advantage that the auxiliary circuits are so simple that a comparatively inexperienced person can readily detect and remedy any defect of adjustment. The arrangements of the circuits and relays for direct current for these three relay systems are shown in Figs. 2, 3 and 4. In the case of control of A. C. motors, this result cannot be secured with multiple relay control in such a simple manner, for the reason that the secondary current is in general of such low frequency as to be unsuitable for the operation of load limit relays. The desired result can be accomplished, however, by a different arrangement, almost as simple.

Master Controllers for use with current limit controllers, as furnished by the General Electric Company, are arranged for two different degrees of automatic control. In the one case, the master controller is reduced to the simplest possible arrangement and is used only for starting, stopping, and reversing the motor, but never for giving control for operation at reduced speeds. Master controllers of this sort are usually applied to service on the roll tables which carry the billets to and from the rolls. If desired, provision can be made for one slow speed point, so that the machines can be adjusted conveniently. When current limit control is applied to hoist service, however, it is necessary to give the operator more control over the acceleration of the motor. Master controllers for hoist service are consequently arranged with several hand control points—usually the same number as there are resistance points, except for the current limit control. The operator has the same control over his equipment that he would have with a drum controller. Figs. 2, 3 and 4 show the simpler of the two forms of master controllers.

Control Equipments for 2000 and 6000 H.P., 6600 Volt Induction Motors for Indiana Company's Rail Mills at Gary

In designing the above equipments, not only were the sizes of the induction motors controlled beyond anything previously attempted, but the specifications of the control presented many novel features. The service required a very large flywheel effect for most of the motors, and it was clearly recognized that with the well known characteristics of the induction motor, even though the flywheels were very large, there would be large fluctuations in current, unless some means were employed for automatically introducing resistance into the motor circuit whenever the load was sufficient to cause as small a change of speed as 2 or 3 per cent. Under ideal conditions, these automatic features might be so adjusted as to be in operation continuously, regulating the current taken by the motors so that the demands on the source of supply for any one motor would be very uniform, the motor and its flywheel meanwhile accelerating and decelerating around a point just below synchronism. The motors themselves required such large currents in their secondary circuit, even with the high voltages adopted, that special contactors were developed. The rheostats were laid out so as to give 16 control points, and were specially arranged in multiple delta, the successive values of these resistances being such that as

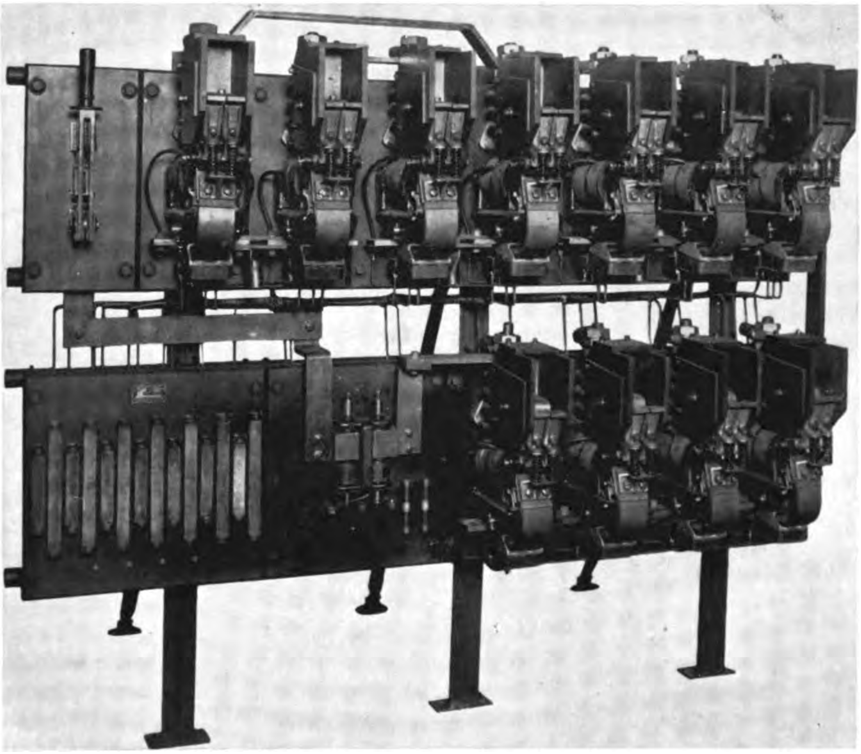


Fig. 6. Automatic Control Panel for 1200 H.P. Induction Motor

each contactor closed, the rush of current through it would be approximately one fourth of the normal output current of the motor. This arrangement accomplished several economies. First, the contactors themselves, although very liberally designed, were not called upon to carry anywhere near their full rated current at any time; and then it was found that the motor rheostats, thus arranged, naturally adapted themselves to a very conservative continuous rating, while the cables and connections for the contactor and rheostat, by no means an inconsiderable item, were greatly reduced in cost.

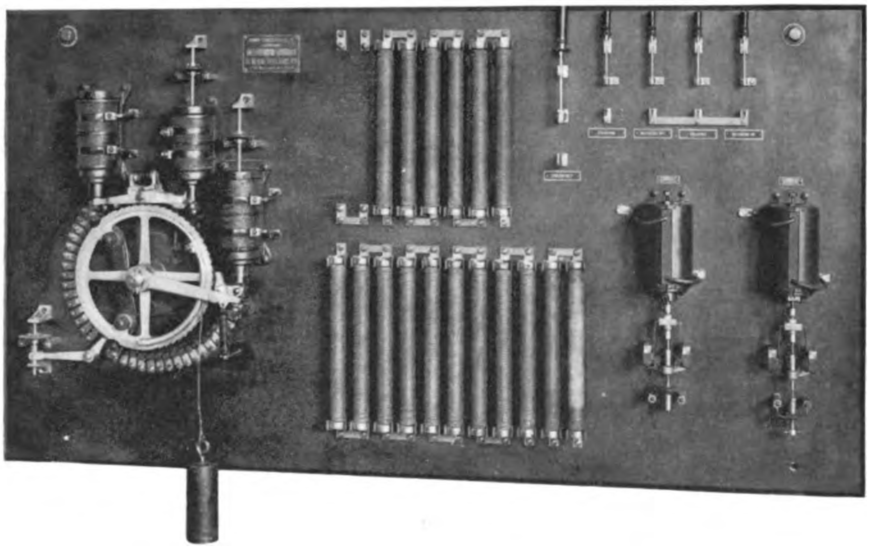


Fig. 7. Regulating Panel for 6000 H.P. Induction Motor

The control apparatus for each motor consists of several groups of apparatus: first, the primary control embracing the oil switches, series transformers, primary relays, etc.; second, the secondary control apparatus consisting of the rheostats, contactors, and regulating panel; and third, the master controller. In the mill as constructed, the motors, together with their oil switches and secondary controlling apparatus are located in a room separated from the rolling mill proper by a partition through which, of course, the motor shaft passes to the rolls. The master controller is located at a point remote from the motor, overlooking the rolling machinery. It can be seen that under these conditions the operator has to depend very largely on the automatic features of the control, which are, of course, located so far from him that he can in most respects only know of what is happening by the behavior of the rolls while the steel is passing through them. At the same time the attendant in the motor room must be able, in case the motor shows any signs of trouble, to shut down the motor in such a way as to take its control entirely out of the hands of the man at the master controller.

Taking up again the several divisions of the equipment and looking into them more in detail, reference should be made to Fig. 9. The primary switch gear is shown diagrammatically in the upper left-hand corner. The 6600-volt circuit enters through a triple pole type H-3 oil switch, the current then passing through a pair of K-2 oil switches which determine the direction of the rotation of the motor. These are interlocked so that it is impossible for them to either close or open, unless the H-3 switch mentioned above is in the open position. Furthermore, interlocks prevent them from closing simultaneously with each other. An additional oil switch which can be closed only when the H-3 oil switch is opened, and which is furthermore interlocked so that the H-3 switch cannot be closed while it is closed, is for the purpose of connecting the stator winding of the motor to the 250 volt D.C. supply. This group of primary control apparatus comprises also relays to open the H-3 oil switch in case of overload; a potential transformer and a potential relay so connected that the secondary control cannot be operated in any injurious way when the 6600-volt circuit is off; and the necessary current transformers to operate the regulating devices in the secondary control apparatus.

The secondary control apparatus consists of the necessary rheostats arranged in multiple-delta, as shown in Fig. 9; seventeen contactors mounted on pipe supporting framework, and an automatic regulating panel known as the C-210 controller. For the controlling of all this secondary apparatus, D.C. current at 250 volts was adopted as being most suitable and reliable. Several incidental advantages obtainable by its use are worthy of mention. First as to the contactors themselves: it was found desirable to wind their actuating coils with a comparatively coarse wire, and to operate them in series so that the voltages of each contactor coil would be equal to only about 15 volts. It will be noted that this voltage per contactor is so small that when a contactor is thrown into or out of circuit, the arcing is insignificant. It is, of course, necessary to compensate for the different number of contactors in circuit at different speeds. This is accomplished in a simple manner on the C-210-A controller by arranging the circuits so that whenever a contactor is cut into circuit a resistance is cut out of circuit and vice-versa. This keeps the current in the contactor circuit approximately constant at about 5 amperes, and results in a very simple arrangement of the contacts on the regulating device. It will be seen that this regulating device consists of two concentric groups of buttons, each group consisting of 16 buttons, one group of buttons being connected to the contactor coils, and the other group to the contactor resistances. The two groups of buttons are cross connected step by step by a simple arm, which is driven from step to step under the control of the operator and of the automatic devices by direct acting solenoids indicated as notching relays "K" and "L" on this diagram. When circuit is completed through relay "K", this solenoid will pull up into place and open its circuit on the interlock discs, whereupon it will drop to the starting point and the circuit will again be completed, the operation thereupon being repeated. Each time this relay lifts, it will cause the contact

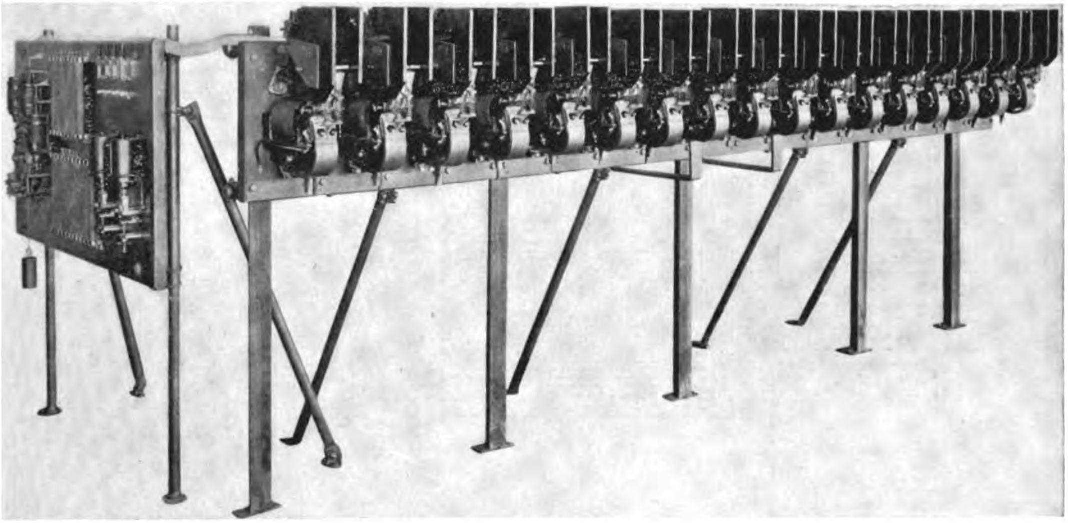


Fig. 8. Automatic Control Panel for 6000 H.P. Induction Motor

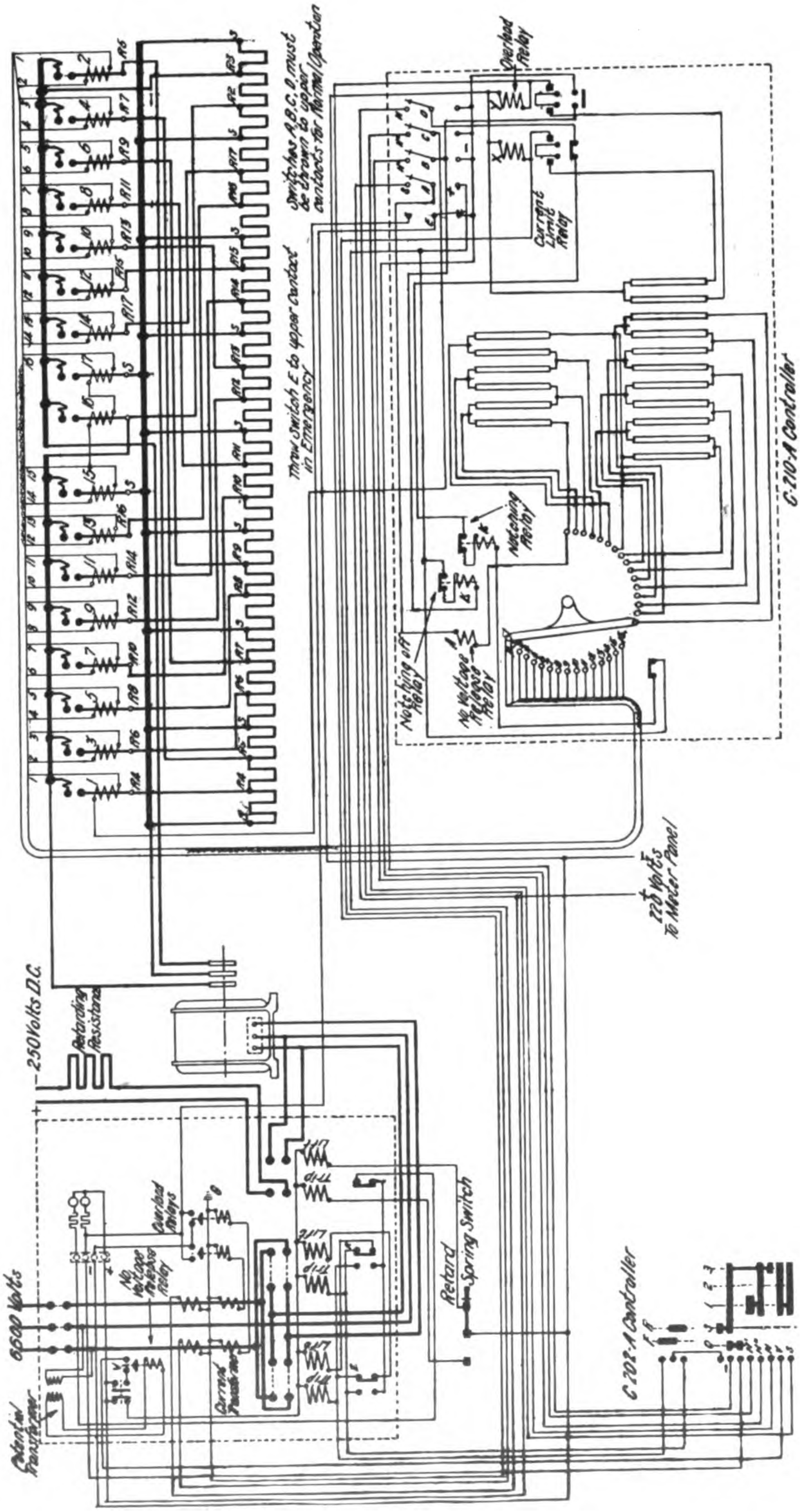

Switches A,B,C,D must be thrown to upper contacts for Normal Operation
Throw Switch E to upper Contact in Emergency
Overload Relay
Current Limit Relay
C-210-A Controller
Notching Relay
Notching off Relay
No Voltage Release Relay
220 Volts To Meter Panel
250 Volts D.C.
Retarding Resistance
Overload Relays
No Voltage Release Relay
Current Transformer
Potential Transformer
6600 Volts
Retard
Spring Switch
C-203-A Controller

Fig. 9. Controller and Motor Connections for 2000 and 6000 H.P. Induction Motors

arm to advance one step, thereby energizing one additional contactor. Relay marked "L" operates in a contrary-wise sense to relay "K". Every time it operates, it will permit the contact arm to move in a retrograde direction, one step at a time, the driving force being a weight and chain which drives the contact arm through the agency of a grooved pulley. This weight also serves to return the contact arm to the off position whenever the 250 volt current fails. The mechanical relation of these parts can be clearly seen from Fig. 7. The above described relays are made automatic in their action by the overload and current limit relays on the right hand side of the controlling panels. These relays are indicated as "X" and "Y". Assuming that the operator, by means of his master controller, has completed the circuit of the relay "K" mentioned above, it will be observed that the circuit for this relay passes through contacts on the current limit relay "X" which are closed unless the current in this overload relay is sufficient to open them. This current relay, it will be observed, is in circuit with one of the series transformers previously mentioned. This relation of parts is such that full load current on the motor will interrupt the process of cutting out resistance. The operation will, however, be renewed when the load is sufficiently decreased.

Relay "Y" it will be seen operates in conjunction with relay "L." Assuming that an overload occurs, relay "X" will operate and then, if the load is sufficient, relay "Y" also. This connects the notching relay "L" into circuit and causes the contact arm to move backward one step at a time until a sufficient amount of resistance is introduced into circuit to decrease the load.

The master controller, of course, is so arranged as to secure all needful control both of the oil switches and of the secondary control apparatus. It has two handles—one reversing handle which changes the circuits to the K-2 oil switches mentioned previously, and another handle for applying and shutting off power. When the main handle is at the off position, circuit is made for the H-3 oil switch so as to open it. At point "S" circuit is made for closing the oil switches so as to apply current to the motor with all resistance in circuit. Points 1 and 2 have no influence on the control, unless the motor has first been started; point 3 completes circuits so that motor will come up to full speed, unless an overload occurs. If, however, the operator desires to interrupt the acceleration before full speed is obtained, he may drop back to point 2, in which case the motor will run continuously with whatever resistance was in circuit on point 3. If he passes back to point 1, resistance will be introduced into the motor circuit step by step until the total resistance is in circuit. The functions of the master controller are duplicated by switches A, B, C and D on the C-210-A controller, so that all the apparatus may be tested and adjusted without resorting to the master controller, which is, of course, relatively inaccessible for this purpose. Switch "E" will, when thrown, entirely shut off power, disconnecting the master controller entirely from circuit. The equipment also includes an emergency switch located in the rolling mill, which can be thrown in case of emergency. When this switch is thrown, which should be done only in case of an accident such as to render it necessary to stop the motor quickly, the motor will be disconnected from the source of supply. The resistance in the secondary will be cut into circuit and direct current will be applied to the stator windings in the motor. This will bring the motor to rest quickly, thereby causing the motor to generate alternating current, which is dissipated in the controlling rheostats.

ROTARY CONDENSERS IN STEEL MILLS

By A. L. Jones

Power and Mining Engineering Department,
General Electric Company

The recovery and use of waste gases from blast furnaces is now receiving the earnest attention of steel mill engineers; for they see, in the effective use of this energy, a possibility of material reduction in the cost of their output. The perfecting of the gas engine and other devices for utilizing furnace gases, and the high economy of the steam turbine, are forces making for the centralization of the power plant near the blast furnace. The difficulties and losses incident to the transmission of great volumes of steam to large rolling mill engines, distantly located, stands in marked contrast to the efficient means employed for electric transmission of power to motors driving the rolls.

Electric drive in steel mills is no longer an experiment, it has earned its place and come to stay. Great reductions in operating force, as well as considerable saving of time, followed the installation of motor driven unloaders and bridges. On overhead travelling cranes and motor driven charging machines, the electric motor has proven its reliability. Motors have replaced engines on tables, shears, pumps, etc., until nearly every modern steel mill uses electric power for practically all its operations, except driving the main rolls.

The future use of motors on the heavy rolls is inevitable, and some noteworthy pioneering in this direction has already been done. The same reasons that forced the electric motor to the front for minor operations, will effect the use of larger units on rail, merchant and other rolling mills, and produce correspondingly great economies. The tendency of steel mill practice seems to be toward the specialization of a given mill to a single product, doing away, where possible, with reversing rolls.

The early installations of electric motors in steel mills were generally of the direct current type. As the number and size of the units increased, the difficulties of transmitting large amounts of power at the low voltage necessitated by direct current began to be felt. Commutators given the best of care are a continual source of trouble, and their abolishment from steel and cement mills will greatly reduce "motor troubles". The induction motor, due to its simplicity, substantial construction, great overload capacity, absence of commutator, and the fact that it can be wound for high voltage in the larger sizes, is peculiarly fitted for driving heavy duty rolls. For reasons of simplicity and efficiency of transmission, it is to be expected that large motors of the induction type will gradually supersede steam engines on the rolls. Every steel mill feels the necessity of securing uniformity in generating equipment, and with the use of large induction motors on the rolls and alternating current mill type motors for driving the auxiliaries, the desired uniformity is possible. The introduction of these motors, with characteristics for this work equal to those of the direct current motor but surpassing the latter in efficiency and durability, will mean that mills of the future will be equipped with alternating current generators and induction motors throughout.

There is one characteristic of the induction motor that is often overlooked which, if it is anticipated and understood, can be readily taken care of. The induction motor takes a certain definite current from the line regardless of the load. This current serves to magnetize or excite the motor and is nearly wattless. It lags practically 90 degrees behind the line voltage, that is, is at right angles to the energy current or the current utilized by the motor for power. Fig. 1 illustrates the relation which the power and magnetizing components bear to each other.

In this figure, AB is the magnetizing component, which is always wattless, and CB the power component. The angle ACB gives the phase relation between voltage and current, the cosine of this angle, $\frac{CB}{AC}$ being the power factor of the circuit.

It is evident from the figures that if the load is reduced, the side CB (power) is shortened and, since AB is practically constant, the angle of lag ACB is increased. It therefore follows that the cosine of this angle, or the power factor, is reduced. The figure clearly shows the reason for the low power factor of induction motors on fractional loads, and also shows that since the magnetizing current is practically constant in value, the induction motor can never operate at unity power factor. With no load the side CB (real power) is just sufficient to supply the core loss, frictional and windage losses. If this power component is represented by DB, since AB remains constant, the power factor is reduced to 10 or 15 per cent., and the motor takes from the line about 30 per cent. of full load current.

The magnetizing current required by the motors, unless otherwise provided for, must be supplied by the generator. It is generated without an increase of power output above that required to supply the power component. In increasing the total current, however, it slightly augments the copper losses, but this slight increase need not be considered from the standpoint of the engines. In other words, as far as the prime mover is concerned, the magnetizing current for the motors is supplied practically without cost. It can not, however, be neglected. The wattless component increases the total current, or k.v.a. output, as shown in Fig. 1. The armature conductors of a generator will safely carry current up to an amount corresponding to its rating, while currents in excess of this will cause overheating. As far as heating of the armature conductors is concerned, it is immaterial what proportions of power and wattless components go to make up a given total current, since the heating corresponds to this total. The proportion of wattless and power components, however, do have a decided bearing on the energy which a generator can supply. The power factor gives the proportion of the total current or output which is available for power. A generator of 100 kw. capacity, when supplying an 80 per cent. power factor load and delivering full current, will drive 80 kw. of load; thus 20 per cent. of the generator capacity is unavailable. With a 70 per cent. power factor load, 30 per cent. of the capacity can not be utilized. If engines and boilers are of the same capacity as the generators, 30 per cent. of their respective capacities must stand idle.

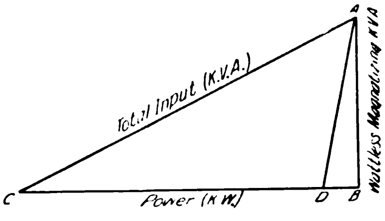


Fig. 1

It should be remembered that the power factor of the generator is determined by the wattless magnetizing current required by the inductive load, and further, that a power factor of less than unity value has the effect of rendering unavailable part of the generator capacity. If all the magnetizing current can be supplied from some source external to the generator, the latter will operate at unity power factor and its whole output will be available for power.

Synchronous motors, as explained below, can be used to supply magnetizing current to induction motors, thereby removing this burden from the generators. Such a motor, of course, has to be separately excited from some direct current source. There is, however, a critical value of field current at which the current taken by the synchronous motor is at unity power factor. If excitation below this value is supplied, the current taken from the line becomes lagging, and the effect on the generator supplying the motor is the same as if the motor were of the induction type; that is, the generator must make up the deficiency in excitation. If on the other hand the field current is in excess of the proper value, the motor draws leading current, and the effect is as if it had more excitation than it needed; this excess being delivered to the system, where it serves to excite or magnetize induction motors and relieve the generators. It follows that if enough leading current is supplied by over-excited synchronous motors to furnish magnetizing current to all the induction motors of the system, the generators will operate at 100 per cent. power factor.

A synchronous motor without mechanical load, and having its field over-excited to deliver leading current for exciting induction motors in other parts of the system, is called a rotary condenser. Such a machine may be located near the induction motors and used to supply the excitation needed by them, thus avoiding the flow of this wattless current through the transmission system and the burdening of generators therewith. In cases where a considerable number of induction motors are concentrated at some distance from the generating station and the conductors necessarily become of considerable size, by supplying the magnetizing current practically at the motors the line current will be reduced and a considerable saving in copper effected. What is more important, however, the generator is not burdened with this wattless current, and its full capacity is available for power. Locating the condenser at the generating station relieves the generator, but the wattless current still has to be transmitted over the conductor net work.

A system of induction motors working on the fluctuating load of a steel mill will have a power factor probably not in excess of 80 per cent., and this fact should be squarely faced, and steps taken to neutralize its evil effects. One of the methods of caring for loads at low power factor is to put in a generator of a size sufficient to carry all the current required by the motors, and to drive this generator with an engine only large enough to supply the power component of the load. If the anticipated power factor is 80 per cent., the normal output of the engine should be but 80 per cent. of the normal capacity of the generator.

In planning an installation of generators for supplying an induction motor load, we are confronted with the necessity of taking care of the idle current either by extra generator capacity, as just pointed out above, or by supplying the wattless magnetizing current from over-excited synchronous motors: which method is to be preferred depends on circumstances. If the generators are of slow speed, and hence very large for their output, it will probably be cheaper to put in a high speed rotary condenser. If the load is at the end of a long feeder or transmission line, a condenser installed near the motors would probably be the better arrangement, as this would save circulation of idle current through the transmission line and generator.

The rotary condenser can supply magnetizing current to a system of induction motors, wholly or in part. A given amount of magnetizing current so supplied relieves the generator by a corresponding amount and raises its power factor. The gain in power factor of the generator, however, is not proportional to the amount of leading current supplied; a given amount making a considerable difference at low power factor, but producing much less effect when introduced into a system already at high power factor. Proof of this statement and its bearing on the question of compensation for low power factor can be seen by the aid of Fig. 2.

Let OA represent the normal current output of a generator supplying an induction motor load having a power factor of 71 per cent. The generator, in consequence, operates at the same power factor. The angle AOC measures the angle of lag; this angle decreases as the power factor increases. When the power factor is 100 per cent., OA coincides with OC. The side AB represents the wattless magnetizing component supplied by the generator to excite the induction motors, OB the component which supplies the power output from the motors. To raise the power factor to unity would require the introduction of leading or magnetizing current equal in amount to AB. The capacity of the generator then available for power would be OC. If an external source supplies wattless current to the extent of AD, the triangle OA″ B″ would show the relations in the generator. The power factor would be 95 per cent., and previously unavailable capacity has been reclaimed to the extent of BB″. It is evident that if more leading current, represented by DB, were introduced, the generator capacity B″C would become available. The figure shows that the last few per cent. gain in power factor is dearly bought. Numerical values for the case in hand show that by supplying 60 per cent. of AB from synchronous motors, the power factor is raised from 71 to 95.8 per cent. The remaining 40 per cent., if supplied, raises the power factor only 4.2 per cent., or to unity. It follows that to raise the power factor above 95 or 96 per cent., requires an amount of leading current out of all proportion to the improvement of power factor, or generator capacity reclaimed. Therefore, in general, no effort should be made to raise the power factor above this value.

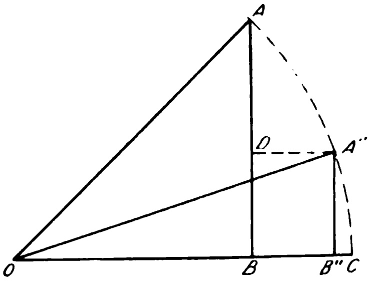


Fig. 2

An over-excited synchronous motor used to supply magnetizing current for induction motors can also carry some mechanical load. The amount of over-excitation of the synchronous motor permissible is fixed by that value of current in armature and field which the motor can safely carry. When the motor is partly loaded, some of its capacity is taken up by power current, the remaining capacity being available for supplying excitation to the system. It can be shown that with certain mechanical loads a larger proportion of leading current is available than with other loads. With the motor driving a mechanical load of 71 per cent. of its rated capacity, and with field over-excited to give full current, 71 per cent. of its rating is available as magnetizing current. This is the most advantageous proportion; for it is seen that, by sacrificing 29 per cent. of the motor output, 71 per cent. of its capacity becomes available for raising the power factor of the system. If the motor carries, mechanically, 90 per cent. of its rating, 43 per cent. is available for leading k-v.a. In many situations it is not practical to put a mechanical load on the motor used for supplying excitation to the system, but if it is possible, considerable capacity for power output is very cheaply obtained.

All motors require excitation, and in this respect the induction motor is no exception. Direct current and synchronous motors require D.C. excitation, while the induction type require A.C. excitation. The rotary condenser may therefore be conceived of as the exciter of the induction motors of the system, and the question of excitation for this type of motor should be no more neglected than the excitation for synchronous motors. It should be borne in mind, however, that excitation which will raise the power factor of the generator above 95 per cent. need not usually be provided. The induction motor is, perhaps, unfortunate in requiring its excitation in this manner, but this fact should not blind one to its many other desirable characteristics, especially in view of the fact that the needed excitation can be so readily provided.

We have endeavored to show why an induction motor operates inherently at a power factor less than unity; that the cause of this is the magnetizing current required by the motor; and that this exciting current, unless otherwise provided, must be supplied by the generator, with consequent reduction in the capacity available for power. Synchronous motors offer a convenient and satisfactory means of supplying the needed magnetizing current, both in future and in existing plants.

Steel mills, facing as they do low power factor due to fluctuating loads, should carefully consider the effects of this on generating equipment and take steps necessary to neutralize its ill effects.

THE SMALL MOTOR DEPARTMENT OF THE GENERAL ELECTRIC COMPANY

By C. H. Scott

On February 1st, the General Executive Offices of the Small Motor Department were removed from 84 State St., Boston, to the West Lynn plant of the Company. This change has been undertaken for the purpose of bringing together the Executive, Commercial, Engineering and Production Departments, engaged in the design, manufacture and commercial exploitation of small alternating and direct current motors.

It is believed that the closer contact thus effected will measurably increase the general efficiency of operation, and permit of handling the motor business with the greatest degree of rapidity, and with better co-ordination between the several departments involved.

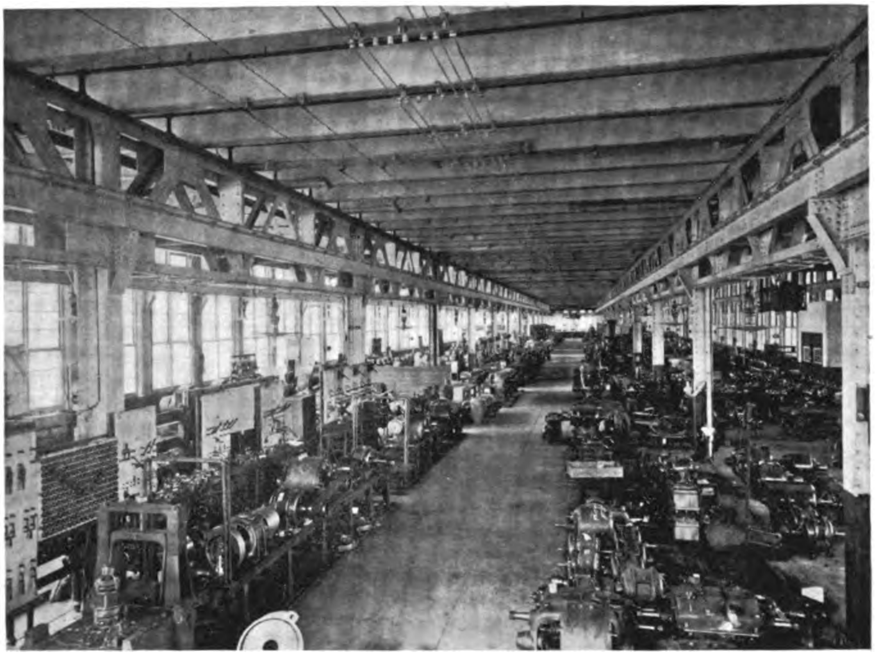


Fig. 1. Second Floor

Before describing the new steel and cement building recently erected to accommodate the ever-growing volume of motor business, it may be of interest to consider briefly the increase in this business which has taken place during the past twelve years, and which has necessitated the present extensive facilities for handling this product.

The Small Motor Sales of the General Electric Company have advanced from less than $50,000 in 1897,—the year prior to the inception of the Small Motor Department,—to over $3,000,000 for the fiscal year ending January 31st, 1908. Expressed in units up to 2 h.p., only 110 h.p. was turned out by the Lynn Works in 1897, all of this amount being direct current apparatus.

The manufacture of induction motors was commenced in 1899, and aggregated for that year only 300 units, with a total of 158 h.p. In 1907, eight years later, the Lynn Works alone turned out 10,517 D.C. units aggregating 42,129 h.p., and 7,913 A.C. units aggregating 18,844 h.p. It should be noted that the record for 1907 is exclusive of both the Windsor and the Pittsfield production, amounting to some 10,000 additional units.

From the above figures it is evident that the General Electric Company has more than kept pace with the rapid advance in the adoption of electric motors for innumerable industrial and general power purposes. In view of the present satisfactory showing, and the promise of still greater demands upon production resources in the near future, the necessity of providing independent facilities adequate to manufacturing needs has been recognized, and has been promptly met in the erection and complete equipment of a separate building, devoted exclusively to motor production. This is entirely consistent with the exactions of the situation, and logically follows the prevailing tendency to decentralize important departments, making them as self containing as possible. The closer association just effected between Executive, Engineering and Production Offices of the Small Motor Department, will enable the General Electric Company to test the advantages of decentralization more thoroughly than has yet been done.

Building No. 74 is a notable advance both in general design and manufacturing facilities, and the following description should be of interest to those who appreciate that, to successfully produce a high grade and perfectly finished product, the design, material and workmanship must be of the best. Furthermore, the tool equipment and sequence of operations should ensure minimum handling and transportation of parts, as well as the most rapid progression through the various machining processes on tools individually driven and especially adapted for given operations. In general, a predetermined scheme of manufacture should be planned and realized, with the object of guaranteeing that quality, speed of production and general efficiency be maintained at the maximum through every working day of the year. Building 74 has been built, equipped and manned to fulfil the above requirements.

Material Dimensions and Arrangement

Fig. 2, showing the western and southern frontages of the Building, indicates its spacious design which provides at once for a generous, natural illumination of the interior, ample ventilation, and abundant space for future enlargement.

The frame and floor timbers of the building are of steel; the walls, roof, and floor filling of concrete. The building is absolutely fireproof, even to details of switchboards, benches, stock room racks, etc.; a sprinkler system affords still further fire protection. The total length of the building is 520 ft. and the width 80 ft.; the area of each floor being 40,800 sq. ft. The total area of the three floors, including towers, is 138,400 sq. ft., or 3.2 acres. On the east side of the building (not shown in the illustration), nearly 9000 sq. ft. are devoted to elevator facilities, and, in addition, generous provision has been made on each floor for large and modern toilet, wash and cloak rooms, and for locker conveniences.

Tool Equipment and Power Supply

The tool equipment is worthy of special mention, as embodying the best and most advanced methods of modern manufacturing progress. The absence of countershafting or overhead belting will be noted from the accompanying illustrations, each and every machine throughout the entire building being individually equipped with the proper size and type of motor, the three accepted forms of belt, gear or silent chain being used as best meets the particular needs of the driven unit. The amount of material finished in a given time has more than justified the capital outlay required to individually equip the 350 machine tools installed; furthermore, the daily "log" record of electric energy consumed, proves, by the abnormally low load factor registered, the large saving which may be effected by eliminating friction losses and delivering energy directly at the point of productive work.

Power supply is available for both A.C. and D.C. service net work, the former at 220 volt, three-phase, 60 cycle, and the latter from a balanced three-wire 250/500 volt system; the maximum voltage being obtained from the terminals of rotary converters, and the neutral derived by a tap taken from the step-down transformers supplying current to the A.C. slip rings.

To indicate the care taken in selecting each tool with the special reference to its fitness for motor manufacture, it may be stated that 226 new machines—a large part of which are of special design—were purchased for the exclusive use of this building. *Each of the large variety of machines adapted to the different processes of manufacture, is equipped with that type of motor best suited to the service demanded;* thus, shunt and compound, direct current and three-phase induction motors are employed where constant speed is required, and for adjustable speed uses, over 200 CR machine tool motors are installed.

Artificial Illumination

A daylight effect and absence of shadow, obtained by the liberal window provision, is almost duplicated by the wealth of artificial illumination provided. An examination of

Fig. 1 will show the lighting scheme for the second floor. Four 480-watt series arc lamps occupy the space from side-wall to side-wall, and equally divide the longitudinal distance between the posts of the supporting bays. In all, a total of 220 arc lamps with concentric diffusers are distributed between the three floors, and furnish light having an intensity between 0.75 and 0.92 watts per square foot, as required. Incandescent lamps are but sparsely used save in a few locations where the intensity or disposition of the enclosed arcs necessitates additional illumination.

General Description of Floors—First Floor

On the first floor, all the heavier parts, such as end heads, frames, pole pieces, sliding bases, etc., are successively machined and finished, the different tools being located in such relation to each other that the work once commenced never moves backward until ready for the "filling" and painting operations at the extreme end of the shop. The assembled main parts are then elevated to the second floor and placed in stock, for assembly with their windings and accessories prior to testing, final painting, and transfer in completed state to the Shipping Department.

In addition to the fine tool equipment, a 5-ton traveling crane serves each of the three bays. Outlets are also provided for compressed air, and, in short, no refinement is omitted in this model floor.

Third Floor

To properly follow the sequence of operation, we must next consider the third or top floor, to which all small parts in the rough, such as brush gear, shafts, copper for commutators, armature and field windings, etc., etc., are carried. These parts are then progressively machined, wound, finished and subsequently transferred to the second floor, where they meet the assembled frames and heads coming from the first floor. The motors are now ready for final *and complete assembly, after which they are* ready to pass successively through stock, test, and ultimately to the Shipping Dept.

Second Floor

In the left foreground of Fig. 1 are shown the sections devoted to government and special A.C. and D.C. tests. In the middle and right hand bays (toward the center of the building), testing space is reserved for standard constant speed A.C. and D.C. motors. To provide load for machines under test, a bank of 48 water rheostats is installed in a separate steam heated building, adjacent to the main building. These rheostats are operated by individual motors, through remote control switches on the various testing boards.

The testing benches and switchboards, with their various accessories, are unusually compact and efficient in arrangement, and are a result of over 20 years experience in the testing of apparatus to insure against possible defects in material and workmanship.

In addition to the space devoted to the Testing Department, stock room and paint shop, ample office space is provided for the Engineering and Production Departments, factory foremen, etc.; adjacent to this is a large drafting room. By this arrangement all departments having supervision over design, manufacture and test are brought closely together. This floor is also supplied with special lavoratory and coat room conveniences.

A 2-ton crane serves each of the three bays of this floor, which, as we have seen, is the place of final assembly, test, painting and shipment of small and large parts in the rough.

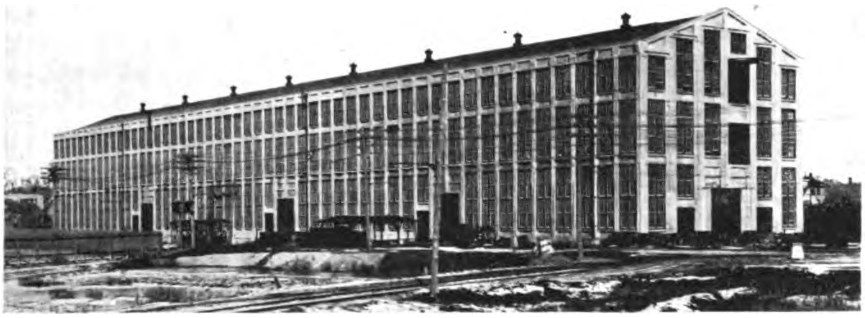


Fig. 2. Building 74

A NEW ARC LAMP FOR TWENTY-FIVE CYCLE CIRCUITS

By G. N. Chamberlin

The pulsations of a 25-cycle enclosed carbon arc are visible to the eye. Light emanating from such a source cannot be considered satisfactory for many classes of artificial illumination, and will not ordinarily be used in any case where a more suitable circuit is available.

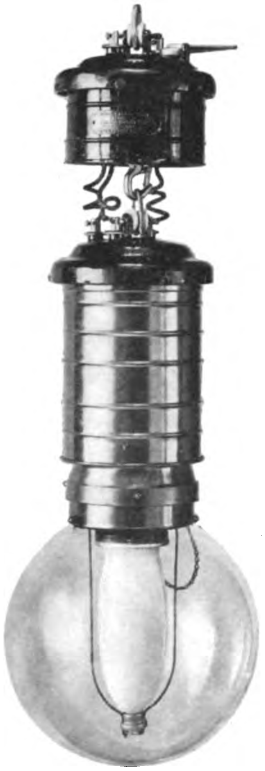


Fig. 1. 25 Cycle Arc Lamp and External Compensator

With the more extensive use of lower frequency alternating current for railroad and stationary motor power, there are parks, railroad terminals, factory buildings, and factory yards to be lighted. For such general illumination the 25-cycle enclosed arc is being used and considered satisfactory. Heretofore, the only enclosed arc lamp available has been a modification of some lamp designed for higher frequency circuits, such modifications consisting of the use of extra or more flexible springs to take up the extreme vibration of the mechanism. A construction embodying the use of very light springs is decidedly questionable as such springs must stand the strain caused by the inrush of starting current.

Figure 1 shows the external appearance, and Figure 2 the mechanism, of a lamp designed to meet these exacting requirements.

The frame is of the well-known two rod type. The mechanism consists of a rocker frame carrying the lamp magnet and suitable current adjusting counterweight. The armature is of standard laminated construction, but is stationary and held rigidly to the lamp base casting. By the use of this considerable weight in the moving element, and by making the armature a part (mechanically) of the lamp frame, all objectionable vibration is absorbed or deadened, thereby permitting the elimination of all springs. The lamp is as quiet and free from vibration in starting and operating as standard lamps for higher frequencies.

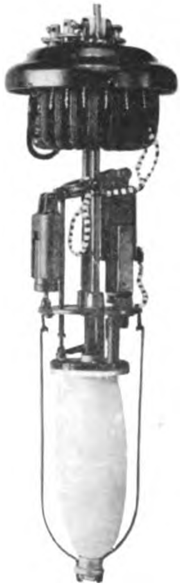


Fig 2. 25 Cycle Arc Lamp, Casing Removed

Where this lamp is to be operated on 220 or 440 volt circuits, an external as well as an internal compensator must be used (Fig. 1), and a third binding post placed on the lamp top, while for nominal 110 volt circuits the lamp is self-contained.

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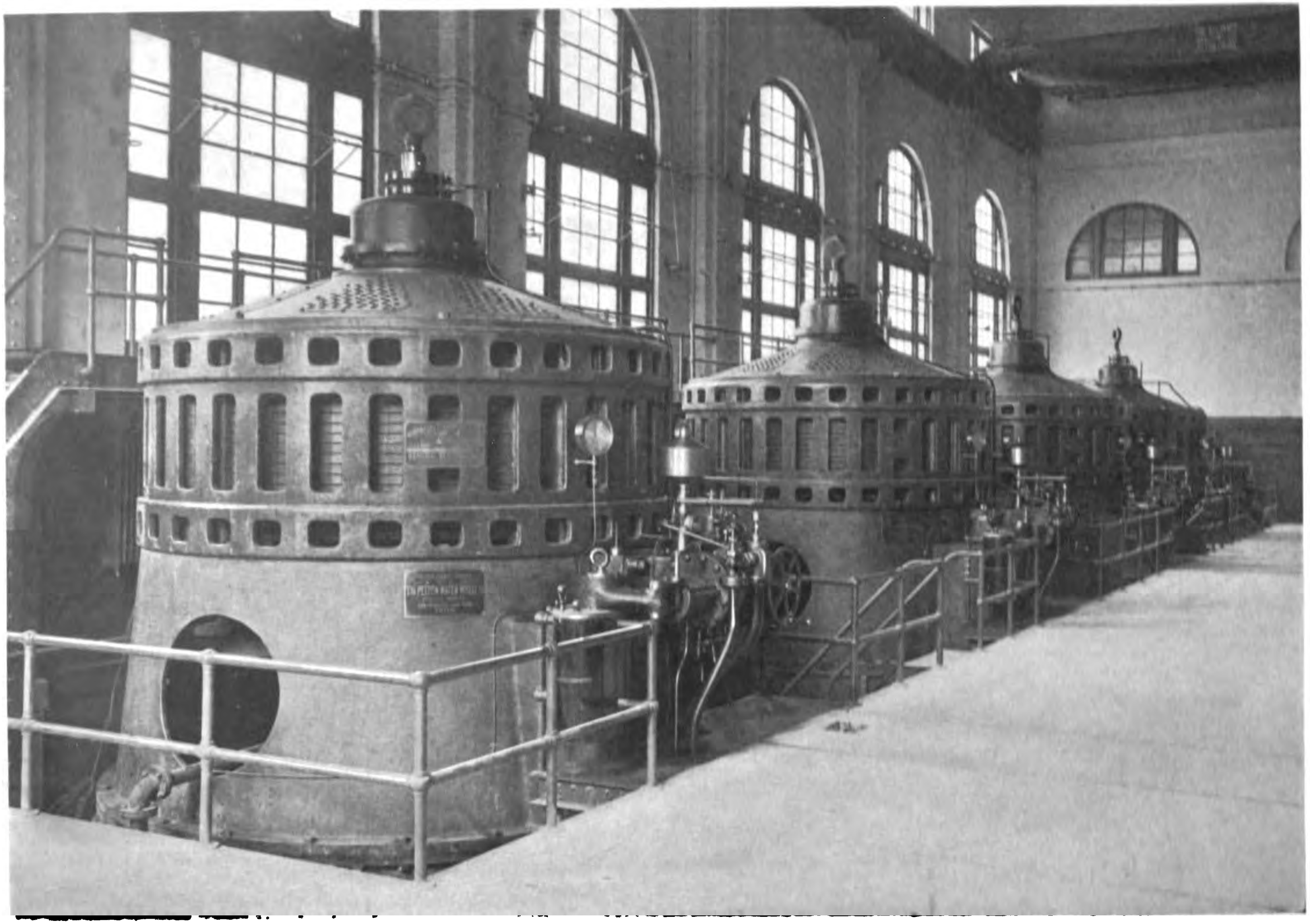

Four 3000 Kw. A.C. Water Wheel Generators and Governors; Power House, Schenectady Power Company, Schaghticoke, N. Y.

GENERAL ELECTRIC REVIEW

ECONOMY TESTS OF HIGH SPEED ENGINES

The paper by Messrs. Dean and Wood, abstracted in this issue by Mr. R. H. Rice, is of unusual value and interest as representing the actual everyday performance of the ordinary types and sizes of high speed, direct connected engine sets, which have been used in enormous numbers, especially in isolated plants, for office and factory lighting and power. The small amount of such information heretofore available has been in strange contrast to the amount of such apparatus in use, and the results are correspondingly valuable. The principal conclusions to be emphasized—as pointed out by Mr. Rice—are the dependence of the everyday economy on the maintenance of moving parts in good condition, and the inability in the ordinary small plant to maintain this condition, either through defective design of the parts, or the fact that small plants cannot economically support an operating staff which will give these parts sufficient intelligent attention. From this it follows directly that the steam turbine, even in small sizes, has a very distinct advantage, and an economy at least equal to that obtained in practice with the engines of the size under discussion; and, unlike the engine, is not dependent for the maintenance of its economy on the attention of the operators. In fact, such attention must be confined, in the case of the turbine, to keeping it in operating condition, it being beyond the power of the operator to materially alter its economy.

The poor results shown in these engine tests may account for the established policy of at least one prominent builder of such engines, who refuses to make any guarantees whatsoever for steam consumption; and the rapid falling off in economy at loads differing from that for which the engines were designed, will probably also account for the variety of sizes often seen in isolated plants, notwithstanding the obvious disadvantages of such a variety of sizes.

Aside from standardization of speeds, details of bases, bearings, etc., to suit standard generators, and improvements in methods of lubrication, the advent of the four valve engine has been regarded as the most distinct advance in such engines. The statement by the authors that "the four valve engines which were built to be more economical than single valve engines have utterly failed in their object" is therefore of particular significance.

Mr. Rice points out the predominating importance of leakage as determining the economy of such engines and the advantage of the compound engine in this respect. It seems not unlikely that one result of such investigations as those presented, will be an extension of the use of the compound engine for driving slow speed apparatus of practically constant load. For the operation of electric generators, however, the development should be in the direction of the turbine drive, on account of the variable load usually imposed by electrical service and the readiness with which the generators may be adapted to turbine speeds.

SKIN EFFECT

In electrical science, as has been the case in so many others, a number of phenomena were foreseen and theoretically determined before their application had any practical bearing. The development in electrical engineering every now and then enforces the necessity of taking into account some of these phenomena, which could be ignored in the earlier stages of the industry. The value of the work that some of the great theorists produced many years ago is then appreciated, since their deductions and formulæ are required for commercial engineering. Amongst other matters considered, that were at the moment only of theoretical interest, can be mentioned the effect that current alternations have on resistance, self-induction, and distribution of current in conductors. Skin effect, as this is usually called, was discussed by Lord Kelvin over 19 years ago, in a certain ideal case.

His resulting formulæ have been left very much as they were then given, and actual values of the various effects produced have not, so far as is known, been at all completely determined. This has been, no doubt, partly due to the fact that the formulæ only apply to ideal conditions not exactly realizable in practice, and also somewhat to the labor involved in evaluating them. References to skin effect are made in a great number of text and hand books dealing with electrical engineering, but with a few exceptions they merely copy one another, giving the increase of resistance, due to the alternations of current, of copper or aluminum conductors at various frequencies. Where more has been attempted, approximate formulæ have generally been derived, which, though no doubt accurate enough, are hardly satisfying, since they give no insight into the physical processes involved.

With the advent of the alternating current railway, skin effect became of importance, in consequence of the rails being used as the return circuit. More lately, when large alternating current furnaces were developed, the conduction of the current to the furnace presented another question in which such phenomena could not be neglected.

Partly for these reasons, the article by Mr. W. E. Miller, entitled "Skin Effect," should prove of some value. In his treatment of the subject, the author has brought the physical aspect of the matter more prominently in view than is usually the case. A mechanical analogy is given which should be helpful in forming a conception of the processes happening inside the conductor in space and time, when a varying electro-motive force is applied to the surface. Like all analogies, this must not be taken too literally, nor applied too rigidly.

The first part of the article, given in this issue of the REVIEW, sets forth the general ideas necessary for the understanding of phenomena in skin effect. The formulæ connecting the current densities at various depths in conductors are given, together with those dealing with the total current flowing in the conductor at any moment. From these formulæ, curves have been plotted to show the effects graphically. Particular attention is called to curves Figs. 3 and 4, which give the instantaneous current values in various layers of a conductor. These curves well illustrate how the current varies at a given moment from the surface to the center.

The second part of the article, which will appear in the next issue, deals more specifically with increase of resistance, and the reduction of self-induction due to current alternations. Hollow conductors are considered, and various curves given showing how much of the conductor core can be removed without altering the ohmic resistance by more than a certain percentage of the total. The phase relations between currents at various depths in a cylindrical conductor are more fully stated, and a curve is drawn illustrating these phase changes. The effect that other conductors carrying current have on these phenomena is also considered; no calculations are attempted, however, for evaluating such effects. The article concludes by giving the conversion factors for reducing the c.g.s. system to practical units.

One of the chief values of the article as a whole is that all calculations are referred to a quantity called *q*, the meaning of which is carefully explained at the commencement of the mathematical portion. By this means the results do not lose generality, and refer to any kind of conducting material of any diameter at any frequency, these factors being interchangeable, as explained in the article.

BUYING CARBON TOOL STEEL

Of the materials purchased in large quantities by all manufacturers, tool steel is one of the most important, and it has remained one of the few which did not seem to be susceptible of scientific purchasing on the basis of definitely specified requirements. Pioneer work in the replacement of tradition by scientific specifications, has been done by Mr. Darke, the Chemist of the Lynn Works of the General Electric Company. On another page there will be found an interesting account of his experience in the preparation and use of specifications covering carbon tool steel. There has always been much mystery made of the manufacture of the higher grades of carbon tool steels; and it has been maintained that so much depended on the raw materials used and on the method of their melting and mixing, that such a thing as a formal specification, defining the composition limits of the steel, was utterly impossible. As the result of two years' use of such a specification in the Lynn Works, this belief has been entirely dispelled, and another item has been added to the long list of materials in which the old methods of buying of "brands" have been supplanted by the purchasing of known material, under the guidance of the chemist.

THE SCHAGHTICOKE HYDRO-ELECTRIC PLANT OF THE SCHENECTADY POWER COMPANY

By John Liston

Undeveloped water powers within short transmission distances of large centers of population are rare in the Eastern States, and all such available streams are now being carefully studied by hydro-electric engineers with a view to their ultimate development.

These facts render a study of the recently completed hydro-electric plant of the Schenectady Power Company at Schaghticoke, N. Y., and the methods adopted in utilizing to the fullest extent some unusual typographical conditions, of interest to those either theoretically or practically concerned in work of this nature.

The problem presented to the engineers in the Schaghticoke (pronounced "Skatikook") development was the utilization of a drop in the Hoosic river of more than 150 ft. in a distance along the stream of about two miles. This drop occurs in a series of small cascades which were individually incapable of profitable development: the extremely irregular course of the Hoosic river at this point, however, brought the problem within the scope of economical engineering solution. (Fig. 1).

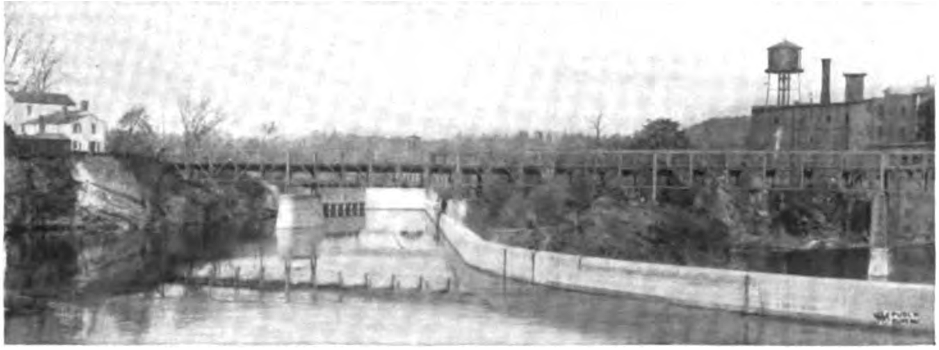

Fig. 2. Dam and Forebay, looking down Stream

A considerable amount of preliminary work was necessary before actual construction could be started, and the rugged character of the river valley, with river banks ranging from 50 to 200 feet in height, rendered some of this extremely difficult. The result, however, has been a highly efficient plant which utilizes practically the total drop of the river, with a normal output of 12000 kw. This power is transmitted with small loss directly to Schenectady, N. Y., a distance of 21 miles.

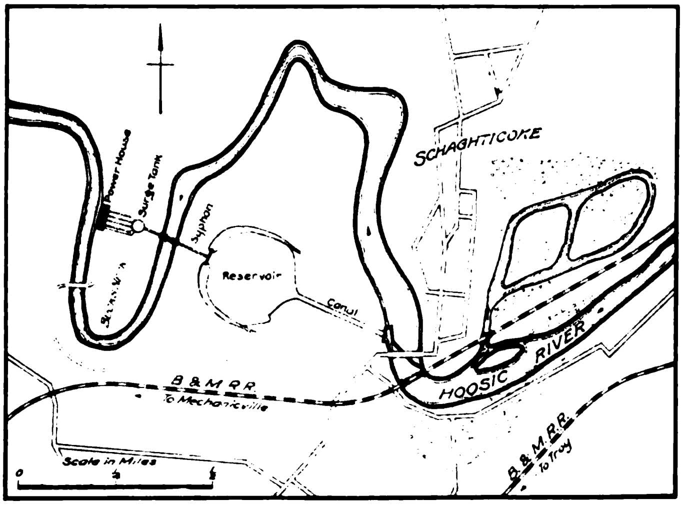

Fig. 1. Map of Schaghticoke District and Power Development

The construction work comprises some exceptional features, as is evident from the following brief description of the development, covering the various details from the river source to the power house tail-race.

In any hydro-electric development the available water supply is naturally of supreme importance, and if the resources of the Schaghticoke plant are examined, we find them to be as follows: The Hoosic (or Hoosac) river rises in Berkshire County, Mass., on the west slope of the Hoosac Mountains; its head waters, near the city of North Adams, Mass., being about 1000 ft. above sea level. The river runs north-westward through southern Vermont and enters the Hudson river about 14 miles above the city of Troy, draining through its course of about 90 miles, an area of approximately 730 square miles: the drainage area back of the Schaghticoke dam being about 600 square miles. No important lakes occur in this drainage basin, and prior to the construction of the dams at Schaghticoke and Johnsonville, there were only two storage reservoirs, situated at Clarksburg and Cheshire near the head waters. In September, 1903, a gauging station was established, the records of which show that, under ordinary conditions, with the storage facilities now provided, the Schaghticoke plant will be enabled to operate continuously at 50 per cent. load factor.

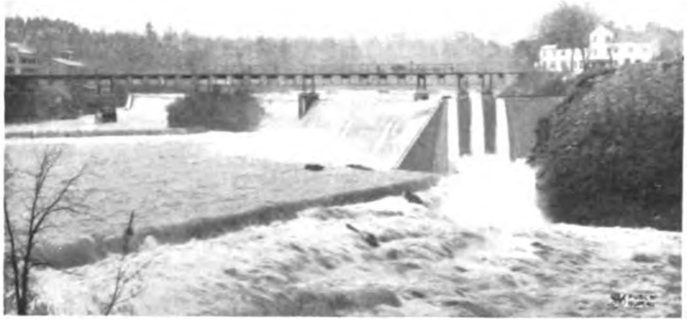
Fig. 3. Looking up Stream. Dam with Water going over Spillway and through Sluice Gates

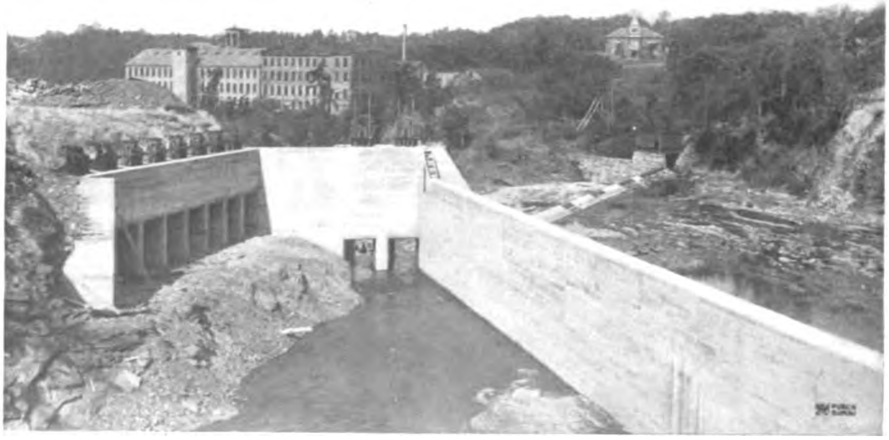
Fig. 4. Near View of Forebay showing Sluice Gates and Canal Intake

The town of Schaghticoke is located in Rensselaer County, N. Y., about 12 miles north-by-east of Troy. Just below the town the river makes two sharp bends (Fig. 1), and across these the water is carried from the Schaghticoke dam to the power house.

The dam (Figs. 2 to 5) is constructed entirely of concrete, and throughout its length rests on ledge rock which has been undercut to afford solid support for the masonry. It is built in 13 sections, with expansion joints between sections; has a net length of 680 ft. on the spillway, with a maximum height from foundation to crest of 29 ft.; and contains more than 9000 cubic yards of concrete. The height of the spillway proper varies from 21 to 24 ft., the difference in the various sections being due to the irregular contour of the river bed; this height can be somewhat increased by the use of flash boards. The thickness of the dam at the base varies from 24½ to 28¾ ft.

Five old dams which formerly operated mills in Schaghticoke have been superseded by this construction, and as a short transmission line has been run between the power house and the town, some of these mills are now realizing for the first time the manifold benefits of electric motor drive.

Starting from the east shore just below the bridge of the Boston & Maine Railroad (Fig. 1), the dam curves in a northerly direction and passes under the Schaghticoke highway bridge at about the center of the river, thence it runs almost due north to the opposite shore where the forebay, sluice-gates, ice chute and canal intake gates are located. A sluice-gate is also provided at the east shore end.

The water impounded by this dam floods the low-land above the railroad bridge, as indicated by the shaded section of Fig. 1, and covers an area of about 145 acres. This reservoir will be supplemented by another, formed by a dam 40 ft. high now nearing completion at Johnsonville, about 5 miles upstream from Schaghticoke. This reserve storage water will flood an additional 780 acres, and the energy available at the dam will be utilized by a second power house, now under construction, to supplement the output of the Schaghticoke Plant. The storage capacity of the Schaghticoke dam is 1230 acre-feet and that of the Johnsonville dam, 8640; the total for the two being 9870 acre-feet.

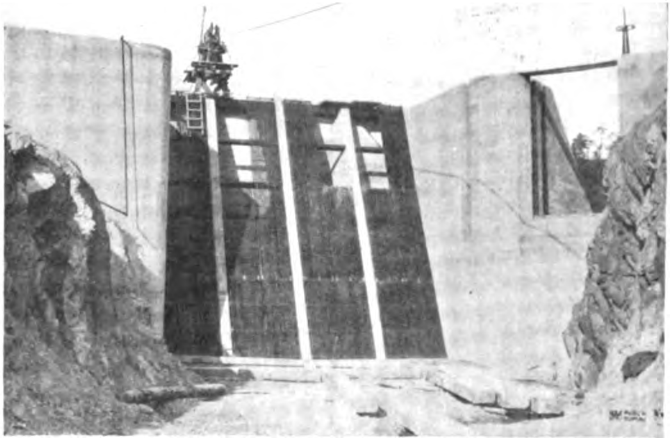

Fig. 6. Lower End of Canal showing Masonry and Screen Racks of Syphon Intake in course of Construction

Following the line of the dam to the west shore, we arrive at the canal forebay (Fig. 4), at which point are located the canal intake gates, eight in number. The masonry work of the gates is all of concrete, reinforced by heavy anchor bolts and firmly braced on the canal side by heavy concrete buttresses. (Fig. 5).

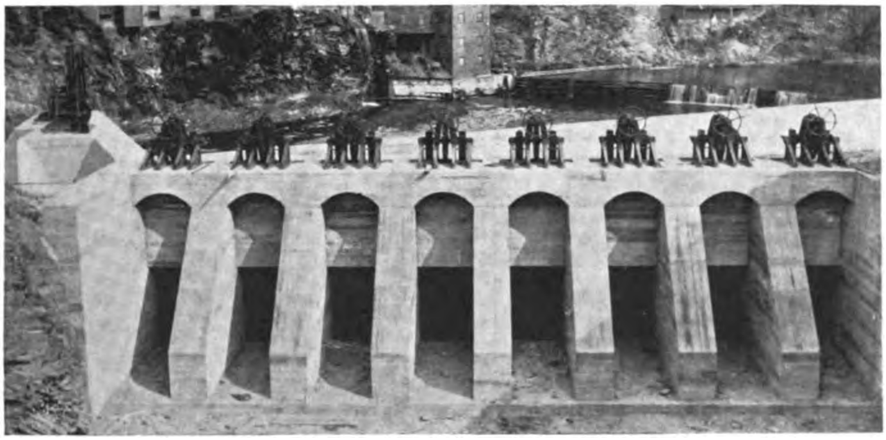

Fig. 5. Bed of the Canal showing the rear of Canal Intake Gates

Each gate is 9 ft. high and 6 ft. wide, and is separately controlled by handwheel-operated

racks and pinions. Measured from the bottom of the inlet gates, the total height of the masonry is 19½ ft.; the total width on the forebay side, 74½ ft.; and the thickness to the ends of the buttresses, 20½ ft. On the down-stream end, where the masonry of the intake gates joins that of the sluice gates, an expansion joint is provided; while for a short distance on the up-stream end, the gates are protected from the effects of the erosion of the river bank by an apron wall of concrete.

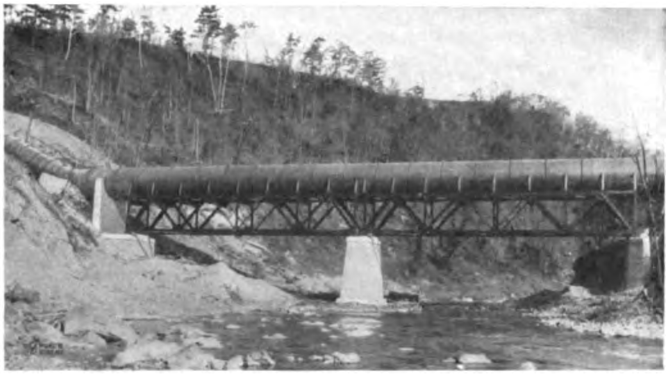

Fig. 7. Syphon Crossing Bed of Stream

The outlet spaces of the sluice-gates (Fig. 4), although located at a lower level, have the same dimensions as those of the canal intake gates, and similar controlling mechanism.

The canal runs from the west bank of the river, directly across the neck of land formed by the first bend in the river below Schaghticoke. It curves slightly toward the north at the start and then runs northwest in a practically straight line, its total length from intake to lower end being somewhat less than half a mile. For a part of this distance the canal is cut through solid rock, while the bottom is bed-rock from end to end. The width of the canal at the surface of the water varies with the contour of the land, but the bottom is uniformly 20 ft. wide.

Where the canal is cut through rock, the sides make an angle of approximately 14 degrees with the *vertical* (4 ft. vertical to 1 horizontal); while in those portions where earth cuts or fills were necessary, the sides slope at an angle of about 26½ deg. with the *horizontal* (2 ft. horizontal to 1 vertical). Where the rock walls of the canal are below the water level, the earth sides are reinforced by heavy timbering to prevent erosion.

Near the lower end of the canal the ground level falls somewhat, and advantage has been taken of this to create an additional reservoir, roughly circular in shape, by building out crescent-shaped embankments from either side of the syphon inlet masonry. These embankments (Fig. 1) are provided with a core, or center wall of concrete, which is 4 ft. in thickness at the base, tapering to a width of 2 ft. at the top. This construction is supplemented on either side by earth and rock filling, the material taken from the canal excavation having been utilized for the purpose.

The embankments extend back toward the head of the canal for about 500 ft. on either side, where they gradually merge into the naturally high level of the land. This reservoir, built with what was practically waste material, adds somewhat to the water storage capacity of the plant and acts as a forebay for the syphon intake.

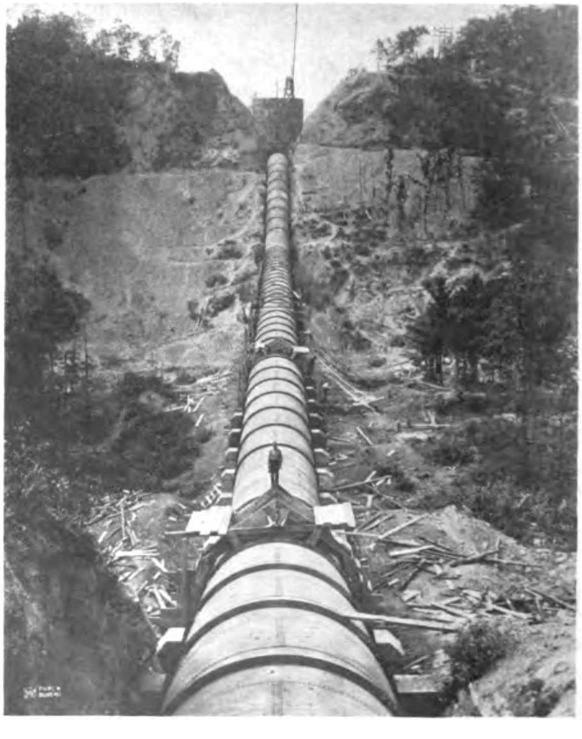

Fig. 8. Inverted Syphon from Intake End, looking toward Surge Tank

At the lower end of the canal is situated the intake (Fig. 6) for the inverted syphon which carries the water across the river to the surge tank. This intake is 35 ft. 6 in. in width, and is divided laterally into four sections, each of which is provided with heavy iron screens; the actual intake to the syphon being well below normal low water level. The masonry work is all of concrete. In addition to the inlet screens, an ice chute is located on one side of the canal, and a small sluice-gate at the bottom. This latter is used, if for any reason it is desired to drain the canal. Directly in front of the screen racks, two deep grooves in the walls of the intake masonry guide a heavy floating timber ice boom which is free to rise and fall automatically with the level of the water, protecting the screens and preventing the entering of ice into the syphon.

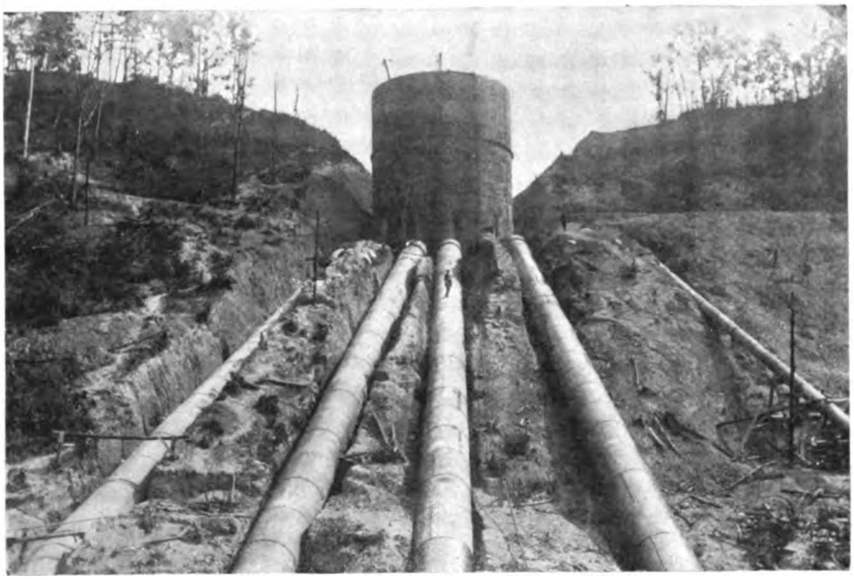

Fig. 9. View from Roof of Power House, showing Penstocks and Surge Tank in course of construction

The inverted syphon at Schaghticoke (Fig. 7 and 8) is about 850 ft. long and consists of a tube 12½ ft. in diameter, made of ⅜ steel, riveted and banded throughout. As stated above, this syphon carries the water from the canal, across the bed of the river, to a surge tank located above the power house.

From the intake at the lower end of the canal, the syphon passes down the river bank, being supported at intervals of 12 ft. by concrete saddles firmly imbedded in the sloping bank. Then, crossing the river on a steel trusswork bridge (Fig. 7) which rests upon concrete piers, it passes up the opposite bank and runs horizontally through an artificial gap cut in the hill known as Bucks Neck. At the far end of this gap the syphon terminates in a surge tank (Fig. 9). Where the syphon crosses the bridge, the concrete shore saddles are succeeded by saddles of steel. In the bottom of the syphon, near the east end of the bridge, a single drainage outlet 18 inches in diameter is located.

The hill referred to above as Bucks Neck forms the second bend of the river below Schaghticoke (Fig. 1). The engineering work included cutting a gap in the top of this hill, of a maximum depth of about 70 ft. To insure the safe transportation of the heavy machinery for the power house equipment, it was also necessary to improve, and in some places reconstruct a considerable section of roadway, and to build a substantial concrete bridge spanning the stream at a point between the lower bend of the river and the power house.

The excavating work necessary in the construction of the canal involved the removal of more than 75000 cu. yds. of earth and about 55000 cu. yds. of rock; Bucks Neck representing the removal of an additional 12500 cu. yards of earth and hard pan.

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High tension automatic motor-operated oil switches with relays connected directly in [illegible]

Disconnecting switches

[illegible] and transmission [illegible]

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volt, three-phase operation, non-grounded neutral. The arrester tanks are installed in the brick and concrete high tension gallery located above and to the rear of the switchboard platform (Fig. 14), while the arrester horn gaps are mounted on the power house roof; this method of installation requiring a special form of roof entrance insulating bushing. Discharge alarm bells are arranged to ring when a phase is grounded.

The characteristics of the aluminum lightning arrester are such that it will take care of recurrent or continuous discharges equally well. The principle upon which it acts is that of a safety valve, the films of aluminum permitting a free discharge when the voltage rises above a predetermined point. A full description of the aluminum lightning arrester and its principle of operation will be found in the June, 1908, REVIEW.

At Schaghticoke the lightning arresters are short circuited at least once a day to insure perfect working order.

In addition to the lightning arrester equipment, the high tension gallery contains the high tension bus bars, oil switches, disconnecting switches, and motor-driven switch operating mechanism, all suitably installed in brick-work and concrete trenches, or enclosed in brick cells.

Except for the turbine equipment and some relatively small portions of the electrical apparatus, the entire power station outfit is of General Electric manufacture and design.

Concrete has been used liberally throughout this development, to combine maximum strength, durability and compactness. The general extent to which it has been employed will be appreciated from the fact that the total amount used, from the dam to the power house, approximates 22,000 cubic yards.

Construction work at Schaghticoke was started in September, 1907, and current was first sent over the transmission line for the purpose of testing it out, about December 1, 1908.

The entire Schaghticoke development was designed and constructed by Messrs. Viele, Blackwell & Buck, Consulting Engineers, New York City.

The transmission line, with its various forms of standard transmission, phase transposition, and strain towers, embodies many features of interest, which will be briefly set forth in the next issue of the REVIEW.

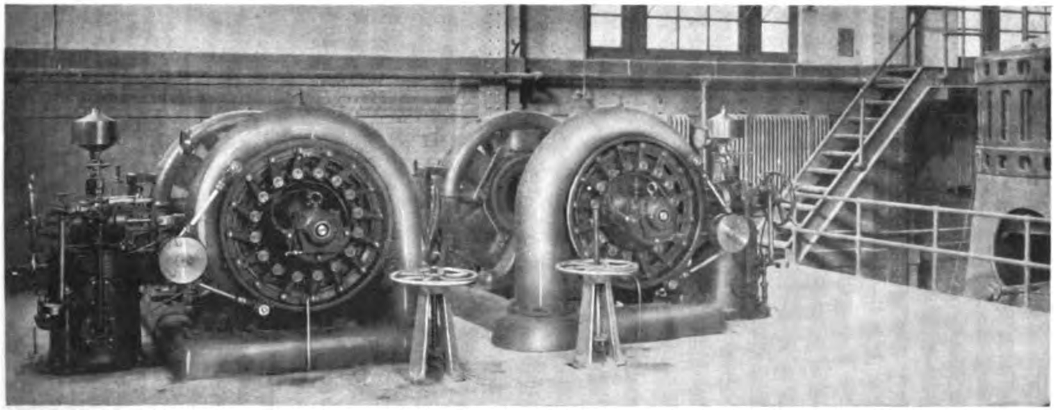

Fig. 15. Water Turbine Driven Exciters, with Controllers and Hand-Wheels for Operating Penstock Valves

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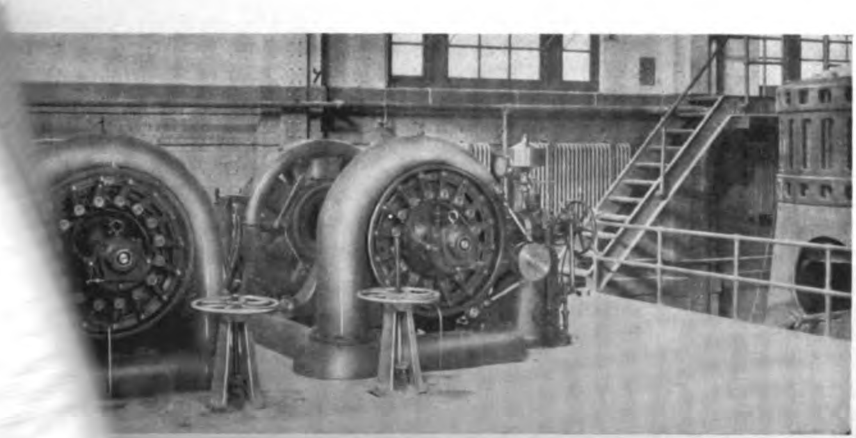

Turbine Driven Exciters, with Controllers and Hand-Wheels for Operating Penstock Valves

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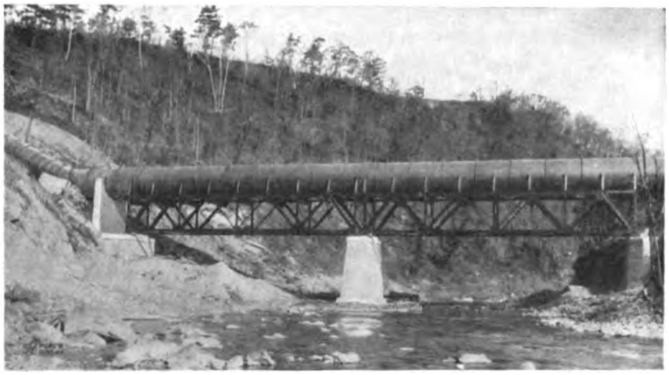

Fig. 7. Syphon Crossing Bed of Stream

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The canal runs from the west bank of the river, directly across the neck of land formed by the first bend in the river below Schaghticoke. It curves slightly toward the north at the start and then runs northwest in a practically straight line, its total length from intake to lower end being somewhat less than half a mile. For a part of this distance the canal is cut through solid rock, while the bottom is bed-rock from end to end. The width of the canal at the surface of the water varies with the contour of the land, but the bottom is uniformly 20 ft. wide.

Where the canal is cut through rock, the sides make an angle of approximately 14 degrees with the *vertical* (4 ft. vertical to 1 horizontal); while in those portions where earth cuts or fills were necessary, the sides slope at an angle of about 26½ deg. with the *horizontal* (2 ft. horizontal to 1 vertical). Where the rock walls of the canal are below the water level, the earth sides are reinforced by heavy timbering to prevent erosion.

Near the lower end of the canal the ground level falls somewhat, and advantage has been taken of this to create an additional reservoir, roughly circular in shape, by building out crescent-shaped embankments from either side of the syphon inlet masonry. These embankments (Fig. 1) are provided with a core, or center wall of concrete, which is 4 ft. in thickness at the base, tapering to a width of 2 ft. at the top. This construction is supplemented on either side by earth and rock filling, the material taken from the canal excavation having been utilized for the purpose.

The embankments extend back toward the head of the canal for about 500 ft. on either side, where they gradually merge into the naturally high level of the land. This reservoir, built with what was practically waste material, adds somewhat to the water storage capacity of the plant and acts as a forebay for the syphon intake.

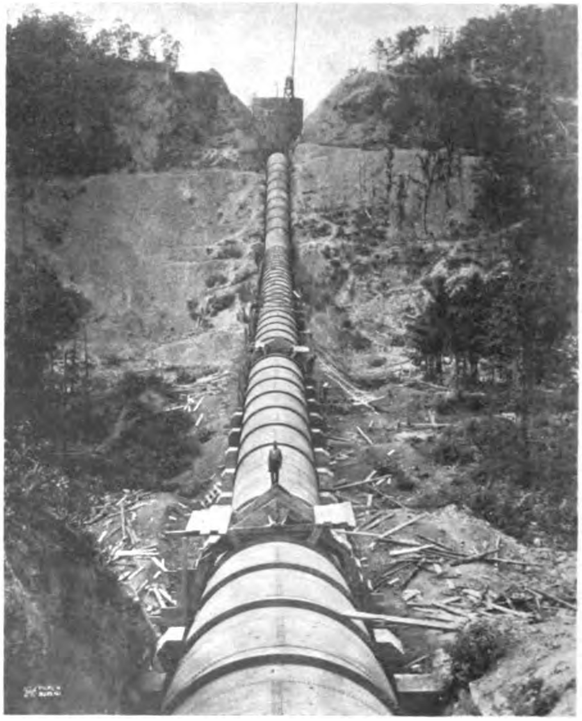


Fig. 8. Inverted Syphon from Intake End, looking toward Surge Tank

At the lower end of the canal is situated the intake (Fig. 6) for the inverted syphon which carries the water across the river to the surge tank. This intake is 35 ft. 6 in. in width, and is divided laterally into four sections, each of which is provided with heavy iron screens; the actual intake to the syphon being well below normal low water level. The masonry work is all of concrete. In addition to the inlet screens, an ice chute is located on one side of the canal, and a small sluice-gate at the bottom. This latter is used, if for any reason it is desired to drain the canal. Directly in front of the screen racks, two deep grooves in the walls of the intake masonry guide a heavy floating timber ice boom which is free to rise and fall automatically with the level of the water, protecting the screens and preventing the entering of ice into the syphon.

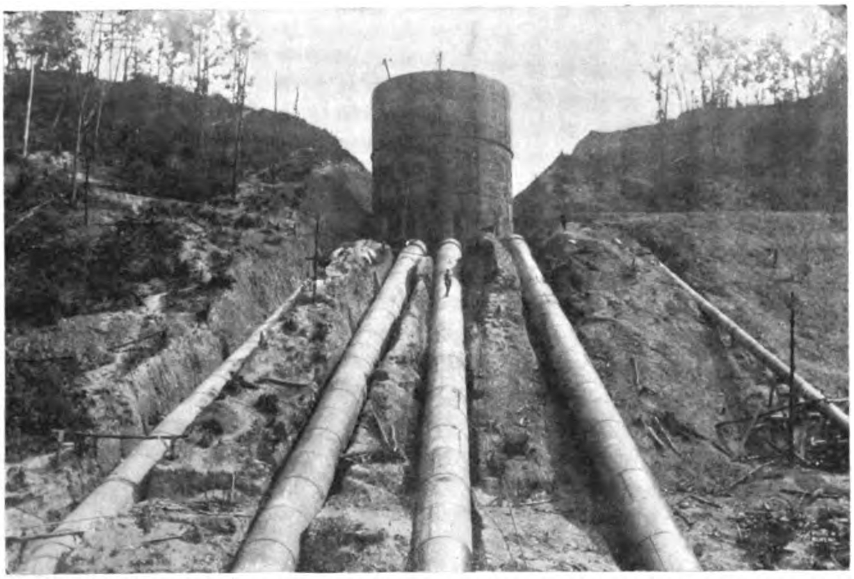


Fig. 9. View from Roof of Power House, showing Penstocks and Surge Tank in course of construction

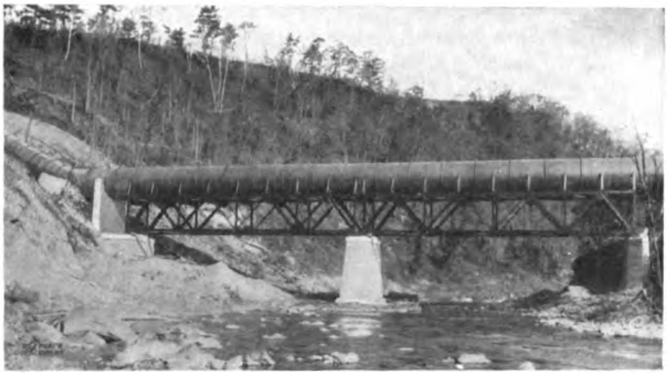
The inverted syphon at Schaghticoke (Fig. 7 and 8) is about 850 ft. long and consists of a tube 12½ ft. in diameter, made of ⅜ steel, riveted and banded throughout. As stated above, this syphon carries the water from the canal, across the bed of the river, to a surge tank located above the power house.

From the intake at the lower end of the canal, the syphon passes down the river bank, being supported at intervals of 12 ft. by concrete saddles firmly imbedded in the sloping bank. Then, crossing the river on a steel trusswork bridge (Fig. 7) which rests upon concrete piers, it passes up the opposite bank and runs horizontally through an artificial gap cut in the hill known as Bucks Neck. At the far end of this gap the syphon terminates in a surge tank (Fig. 9). Where the syphon crosses the bridge, the concrete shore saddles are succeeded by saddles of steel. In the bottom of the syphon, near the east end of the bridge, a single drainage outlet 18 inches in diameter is located.

The hill referred to above as Bucks Neck forms the second bend of the river below Schaghticoke (Fig. 1). The engineering work included cutting a gap in the top of this hill, of a maximum depth of about 70 ft. To insure the safe transportation of the heavy machinery for the power house equipment, it was also necessary to improve, and in some places reconstruct a considerable section of roadway, and to build a substantial concrete bridge spanning the stream at a point between the lower bend of the river and the power house.

The excavating work necessary in the construction of the canal involved the removal of more than 75000 cu. yds. of earth and about 55000 cu. yds. of rock; Bucks Neck representing the removal of an additional 12500 cu. yards of earth and hard pan.

racks and pinions. Measured from the bottom of the inlet gates, the total height of the masonry is 19½ ft.; the total width on the forebay side, 74½ ft.; and the thickness to the ends of the buttresses, 20½ ft. On the down-stream end, where the masonry of the intake gates joins that of the sluice gates, an expansion joint is provided; while for a short distance on the up-stream end, the gates are protected from the effects of the erosion of the river bank by an apron wall of concrete.



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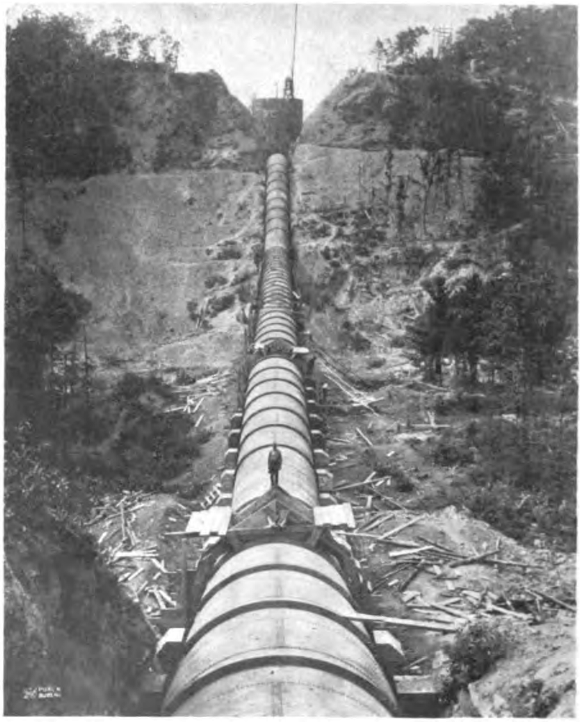

Fig. 8. Inverted Syphon from Intake End, looking toward Surge Tank

At the lower en[illegible]
the intake [illegible]
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surge tank. This [illegible]
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of [illegible]
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Fig. [illegible]

[illegible]

The surge tank into which the syphon discharges is 56 ft. high and 40 ft. in diameter; it is made of steel and rests on a concrete foundation. The thickness of the tank wall varies with the height, being $\frac{9}{16}$ in. for the first 16 ft., $\frac{1}{2}$ in. and $\frac{7}{16}$ in. respectively for the next two sections of 10 ft. each, and $\frac{3}{8}$ in. for the top section of 20 ft.

The tank is provided with gate valves which are located inside, and which control the flow of water to the various turbine penstocks. These valves are arranged for motor operation and also for control by means of hand wheels located on a platform at the top of the tank. The controllers for the motors operating these valves are installed in the power house, each controller being placed beside that turbine which it controls through the penstock valve. The small exciter penstock is, however, controlled directly by hand, the valve being located in the power house for this purpose.

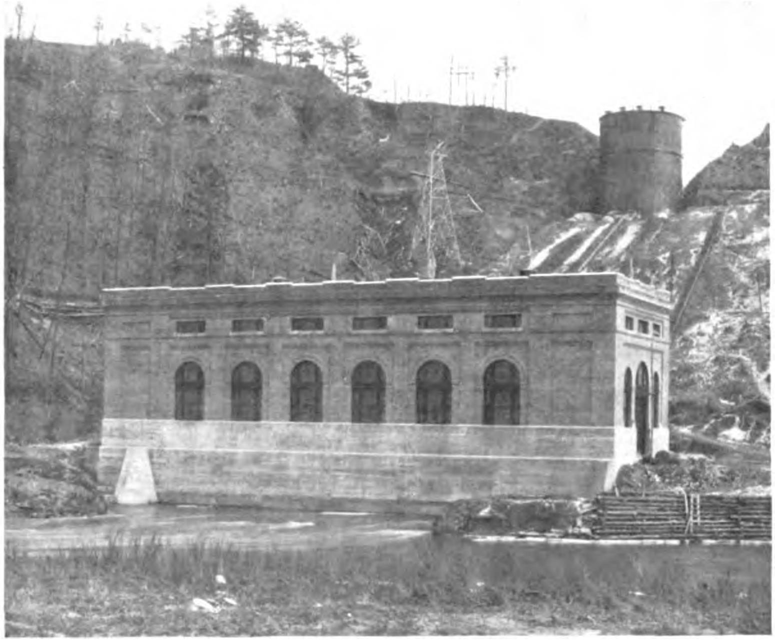

Fig. 10. Power House

From the surge tank the water enters directly into five penstocks (Fig. 9), four of which are 6 ft. in diameter and lead to the generator turbines, while the fifth, which is 2 ft. in diameter, feeds the exciter turbines. The penstock shells are of $\frac{3}{8}$ in. steel, and each is provided with an expansion joint a short distance below the surge tank.

The penstocks descend at an angle of about 27 deg. from the horizontal and give an operating head of from 146 to 152 ft.

The power house (Fig. 10) is of brick and steel construction, with foundations, flooring and wheel-pits of concrete. It is roofed with tile brick and is equipped with a 20-ton motor-driven overhead traveling crane. The penstocks pass beneath the power house floor and lead directly to the wheel-pits where the four vertical "Pelton Francis" generator turbines are located. These turbines are of the inward and downward flow reaction type and are designed for a normal output of 5000 h.p. at a speed of 300 r.p.m. under a head of 146 ft. They consist of three main parts; namely, the revolving element, the stationary vanes or blades mounted in the turbine casing, and the controlling apparatus.

The stationary blades form a ring around the moving blades and are separately mounted on shafts, each one of which is mechanically connected to the governor. By altering the angle of the stationary blades through which the water first passes, the volume of water admitted to the moving blades is varied; a practically constant speed being thus automatically maintained under fluctuating water pressures, since the response of the governor to the slightest speed variation is instant.

These automatic governors are oil operated, a single motor-driven pump delivering the oil at a pressure of 150 pounds per square inch to all the machines. A duplicate pumping outfit is held in reserve for emergencies and, if necessary, the turbines can be hand controlled.

Between the turbines and the tail-race, the water normally drops a distance of approximately eight feet, thus creating an effective vacuum; this is not sufficiently high, however, to develop cavitation effects.

The four generators are of General Electric make and are arranged as shown in illustration on page 146. They are three-phase, 40-cycle, 16-pole vertical machines, each generator having an output of 3000 kw. at 300 r.p.m. and 4400 volts. Special vertical suspension roller step-bearings support the revolving elements of both generators and turbines, and are so constructed as to prevent the throwing of oil. In each machine a small internally located pump provides automatic lubrication. The generators are normally operated in parallel, but, of course, can be operated separately if necessary.

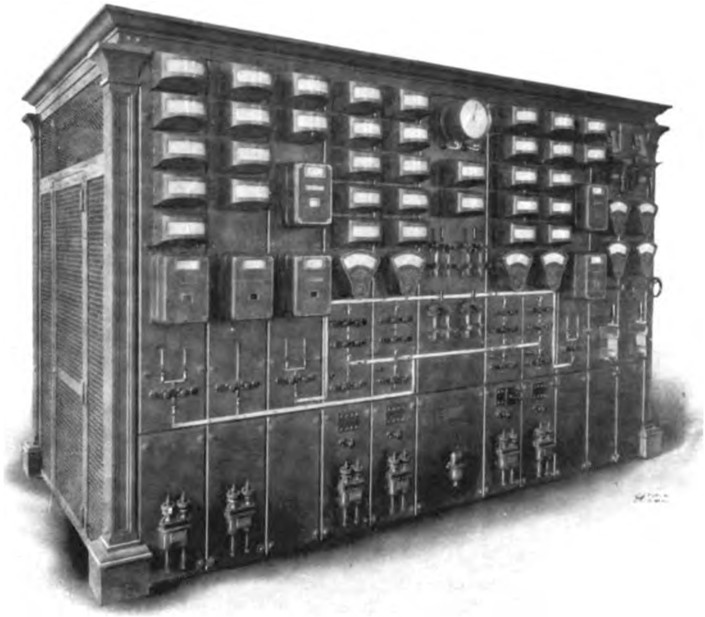

Fig. 11. Switchboard

The exciter equipment is located at one end of the row of generators (Fig. 15) and consists of two General Electric Type MPC 6-pole, 150 kw., 600 r.p.m., 250 volt exciters with commutating poles. They are compound wound, have a full load current of 600 amperes, and are of the horizontal type. Each exciter is direct coupled to a turbine which, except for the fact that it is of the horizontal type, is similar in operation to the generator turbines.

On the ground floor facing the generators is the low tension bus-bar room (Fig. 12) where all of the low tension bus-bars, disconnecting switches, etc., are mounted on a brick wall, each phase being enclosed on three sides by brick work. The instru-

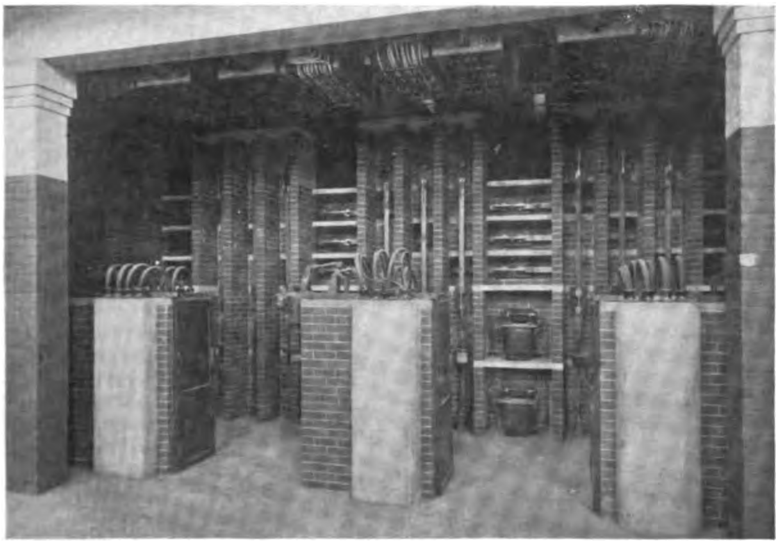

Fig. 12. Low-Tension Bus-Bar Room

ment transformers, relays, and solenoid operated automatic oil switches are also located here.

Directly above this room is the switchboard platform, which extends beyond the wall line and gives an unobstructed view of the entire generator room. The switchboard (Fig. 11) consists of eleven panels on which the customary instruments, switches, relays, circuit breakers, etc. are compactly mounted. In addition to the usual equipment, the switchboard is provided with a complete set of indicating lamps, and mimic bus bars and switches, mounted on the face of the board, so that the connections of the various circuits can be indicated by repeating the actual switching operations on the mimic outfit.

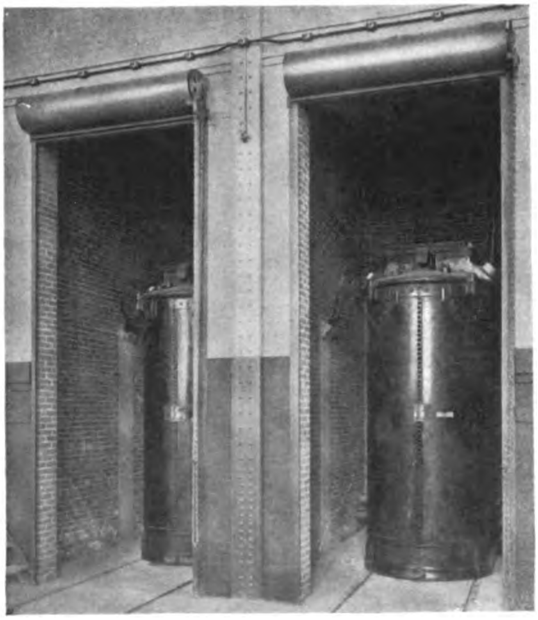

Fig. 13. 3000 Kw. Transformers, 4400/32000 Volts

From the generators to the two three-phase transmission lines the equipment includes the following apparatus:

Between generators and low tension bus bars:

Automatic solenoid-operated oil switches with usual relays and disconnecting switches.

Disconnecting switches.

Between low tension and high tension bus bars.

Disconnecting switches.

Automatic solenoid-operated oil switches with usual relays and current transformers.

Step up transformers.

High tension automatic motor-operated oil switches with relays connected directly in series.

Disconnecting switches.

Between high tension bus bars and transmission line:

Disconnecting switches.

High tension automatic motor-operated oil switches.

It is thus seen that in each line there are seven points at which the circuit may be broken and any section of the equipment effectually isolated.

About 150 kw. at 4400 volts is transmitted to the town of Schaghticoke, where it is utilized in three mills for motor drive, the necessary step-down transformers being located at the mills. A small transformer at the power house also provides 110 volt current for lighting the building. These demands on the station capacity are practically negligible, so that almost the entire generator output of 12000 kw. is available for transmission to Schenectady.

The transformers consist of four 3000 kw., 4400/32000 volt, three-phase, water cooled, oil immersed units of General Electric make. Each transformer is installed in a separate brick cell (Fig. 13) provided with a heavy iron curtain door.

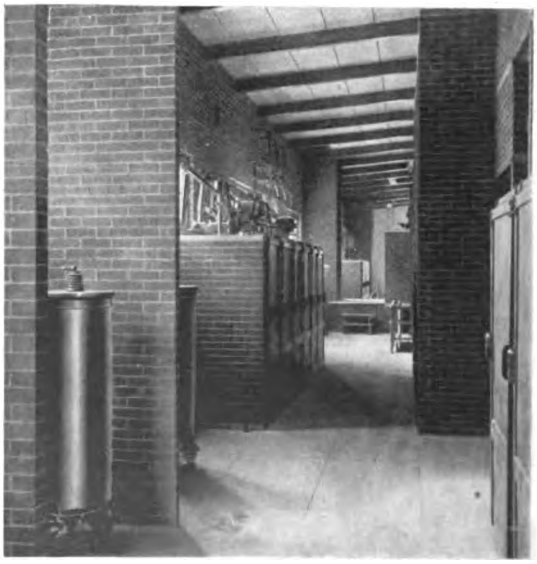

Fig. 14. High Tension Gallery

The present equipment for lightning protection consists of two sets of General Electric aluminum lightning arresters for 35,000 volt, three-phase operation, non-grounded neutral. The arrester tanks are installed in the brick and concrete high tension gallery located above and to the rear of the switchboard platform (Fig. 14), while the arrester horn gaps are mounted on the power house roof; this method of installation requiring a special form of roof entrance insulating bushing. Discharge alarm bells are arranged to ring when a phase is grounded.

The characteristics of the aluminum lightning arrester are such that it will take care of recurrent or continuous discharges equally well. The principle upon which it acts is that of a safety valve, the films of aluminum permitting a free discharge when the voltage rises above a predetermined point. A full description of the aluminum lightning arrester and its principle of operation will be found in the June, 1908, REVIEW.

At Schaghticoke the lightning arresters are short circuited at least once a day to insure perfect working order.

In addition to the lightning arrester equipment, the high tension gallery contains the high tension bus bars, oil switches, disconnecting switches, and motor-driven switch operating mechanism, all suitably installed in brick-work and concrete trenches, or enclosed in brick cells.

Except for the turbine equipment and some relatively small portions of the electrical apparatus, the entire power station outfit is of General Electric manufacture and design.

Concrete has been used liberally throughout this development, to combine maximum strength, durability and compactness. The general extent to which it has been employed will be appreciated from the fact that the total amount used, from the dam to the power house, approximates 22,000 cubic yards.

Construction work at Schaghticoke was started in September, 1907, and current was first sent over the transmission line for the purpose of testing it out, about December 1, 1908.

The entire Schaghticoke development was designed and constructed by Messrs. Viele, Blackwell & Buck, Consulting Engineers, New York City.

The transmission line, with its various forms of standard transmission, phase transposition, and strain towers, embodies many features of interest, which will be briefly set forth in the next issue of the REVIEW.

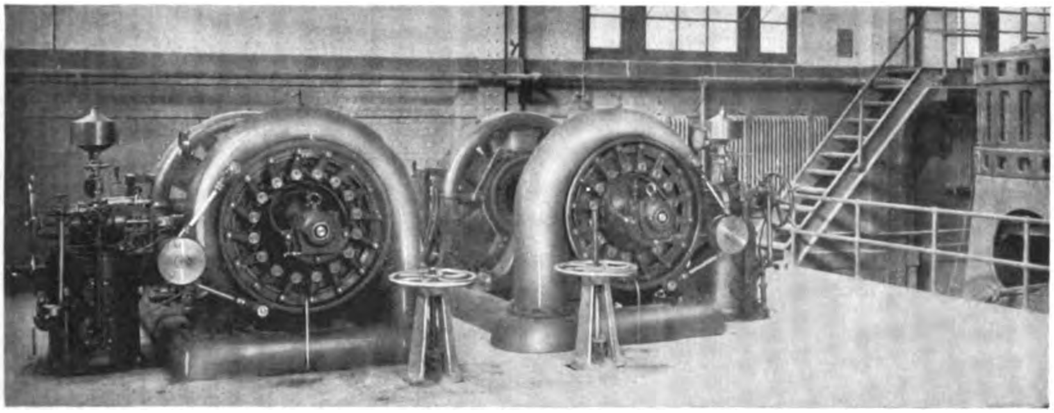

Fig. 15. Water Turbine Driven Exciters, with Controllers and Hand-Wheels for Operating Penstock Valves

REMINISCENCES OF EARLY ARC LIGHTING APPARATUS*

By Dr. E. W. Rice, Jr.

Vice-President, General Electric Company

In the early days, the output of the different companies was exploited as "system" under the name of the inventor, as for example, the Edison System, Weston System, Brush System, Thomson-Houston System, Maxim System, etc. All of these, excepting the Edison System, consisted of an arc dynamo and arc lamps operated in series. They were divided into two classes known as the "long arc" and the "short arc." Brush was the exponent of the "long arc" system, and he was one of the earliest and most successful inventors in the arc light field. In 1880, he had already succeeded in producing an arc dynamo capable of operating 16 arc lamps on one circuit. These arc lamps were of the so-called "long-arc" type; that is, the lamp consumed about 45 volts with a current of about 10 amperes, or as it was called in those days, 10 "Webers." These machines were selling quite rapidly and the business of the Brush Company was most prosperous. The machines were well constructed mechanically and electrically, considering the state of electrical knowledge at that time. The arc lamps had what was known as the "differential" type of magnet for feeding the carbon. It is difficult at this date to understand the situation. It may be partly appreciated, however, when it is stated that the Brush patents purported and were actually believed to cover any form of differential control for feeding the carbons. They also controlled any form of cut-out operated by the shunt circuit. His dynamo was of the so-called "open coil" type, which was thought to be more efficient than the "closed coil" type represented by the Gramme ring and the Siemens or drum type winding. The Brush patents were supposed to cover any form of dynamo of the "open coil" variety.

Weston was exploiting a machine of the "closed coil" type exactly similar to the Siemens winding which is now so familiar. He advocated the so-called "short arc" which was operated with a current of 18 to 20 amperes with about 30 volts across the terminals of the arc. This so-called "short arc" was really not an arc in the modern sense at all, the carbons being separated only about 1/64 to 1/32 of an inch. It gave a fairly steady light somewhat yellow in quality, but inefficient as compared with the so-called "long arc." Of course, the terms "long arc" and "short arc" were really trade names and purely relative. The "long arc" was merely the usual arc such as one obtains by separating the carbons in the open air to a point where the hissing ceases; with a current of 10 amperes this point is reached with a separation of about 1/16 to 1/8 of an inch. Of course, this was long before the days of the enclosed, flame, or luminous arc lamps which may be truly said to have long arcs.

The Brush machine may be considered as a prototype of the modern two-phase machine, whereas the Thomson-Houston machine was the original three-phase machine: each of these machines being provided with a commutator, Prof. Thomson found that in a three coil machine, he could connect three of the ends together and commutate the remaining three. He called this connection the "common connection." That identical arrangement would now be known as the "Y" connection; and if each of the wires leading to the three segments of the commutator were connected instead to three collector rings, you would have the arrangement now so commonly used in a three-phase generator.

Prof. Thomson invented many forms of arc lamps; but the type which was finally selected and sold in those early days was the "differential," although one in which the series and shunt windings were placed on separate magnets and actuated armatures on opposite ends of a walking beam, in contradistinction to Brush's method of placing the series and shunt windings on the same magnet and depending upon the neutralization of the series winding by the shunt.

The Thomson-Houston system consisted not only of a dynamo and arc lamps of novel construction, but had in addition the entirely new feature of an automatic regulator, which was designed to automatically maintain constancy of current in a series circuit, no matter how many lights were in operation. This constituted a most important, radical and valuable improvement, patents for which were obtained and generally respected for a number of years. The importance of this device may be realized when it is stated that with Weston and Brush machines, if one or two arc lamps were extinguished in a circuit of, say 12 to 16 lamps, the current would increase, and the burning of the remaining lamps would be most irregular and unsatisfactory. In practice it was necessary for the users of these machines to keep a number of arc lamps near the dynamo to be cut-in in case any of the arc lamps on the outside circuit were extinguished for any cause. This lack of self-regulation involved a great waste of power, a useless waste of carbons and a large amount of additional attendance. I think that the regulator constituted one of the most important advantages of the Thomson-Houston system. It insured uniformity of light, minimum attention and increased efficiency; it made the machine and system more reliable and "fool proof." The first machine, built at New Britain in the latter part of 1880, was capable of operating four arc lamps, consuming about 45 volts and 10 amperes each. The next size operated ten lamps, and this was quickly followed by one designed for about 16 to 20 lamps.

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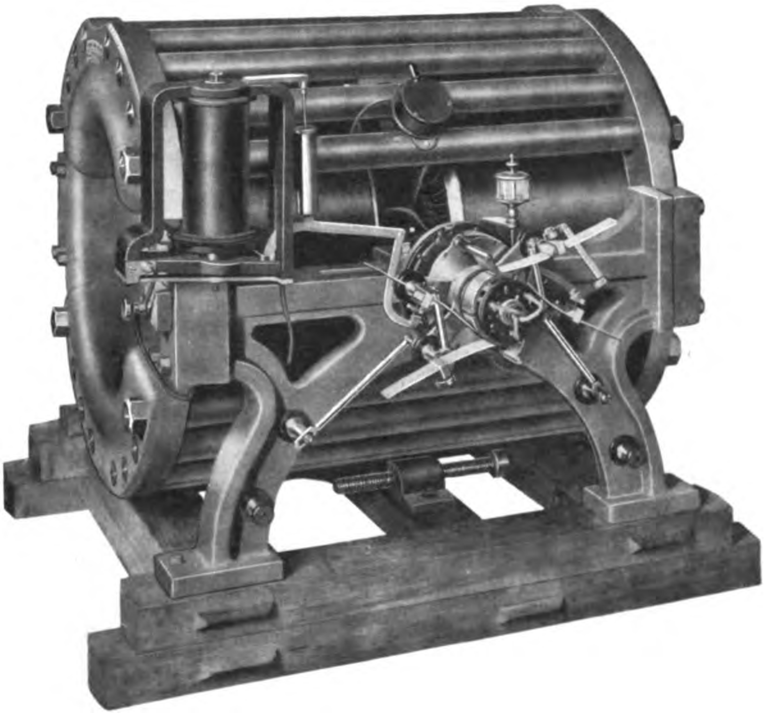
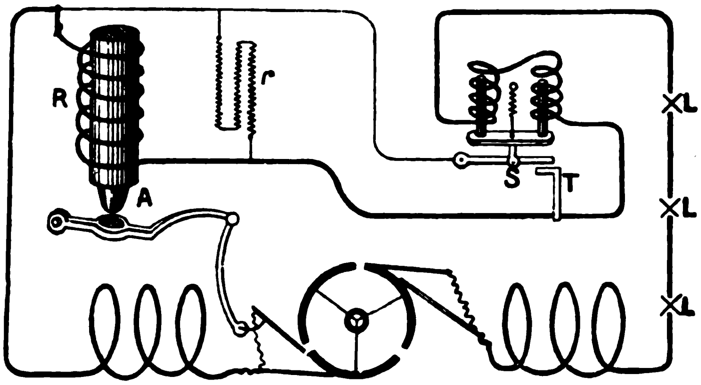
* Paper read before Schenectady Section A.I.E.E.

The attempt to produce a machine with only one commutator containing but three segments, which would operate from 16 to 20 arc lamps, was not at first awarded with success. The Brush machine operated with considerable success with 16 lamps. The connections, however, of this machine were such that the voltage on the commutators was limited, and it had two commutators connected in series, so that it was really equivalent to two 8 light machines. Prof. Thomson could, of course, have adopted the same expedient and wound his armature with two sets of three coils, each set connected to a commutator and these two commutators connected in series. Such a machine was actually constructed and operated satisfactorily; however, it did not please Prof. Thomson, as it considerably complicated the automatic regulator feature. He loved simplicity, and it was fortunate that he did, because in those early days a complex and unreliable piece of apparatus stood little chance of survival.



Thomson-Houston Arc Light Dynamo, showing Regulator and Brush Mechanism

The Thomson automatic regulator was one in which the brushes on the commutator were moved by a motor magnet, and although this method was extremely practicable and simple when applied to one commutator, it became rather complicated when extended to two. The particular difficulty met with was the "flashing-over" or short circuiting of the commutator at irregular intervals; this flashing-over being practically absent with a single commutator operating about 10 to 12 arc lamps, but quite troublesome with 16 to 20 arc lamps. Prof. Thomson was determined, if possible, to maintain the almost ideal simplicity of his machine and made many experiments to ascertain the cause of the flashing-over and the remedy. Finally, in a moment of inspiration, he thought of inserting a cool stream of air at reasonably high pressure between the brush and the leaving segment. reasoning that if an air film or stream could be maintained, flashing-over would be rendered most difficult. A little self-contained blower was therefore designed, which fed the air to the commutator through appropriate nozzles, and when this blower was placed on the machine, it was found that instead of the limit of commutation being some 8 to 10 lights, it was possible to run the machine up to 20 lamps on a single commutator without any signs of flashing. Without the air blast, it was only by very careful manipulation that even a 10-light machine could be made to operate without occasional flashing. The commutator required slight lubrication, in order to prevent undue cutting of the brushes, and if this lubrication was overdone, or the commutators allowed to get dirty, or the brushes badly worn, as was sure to be the case with careless operators, the machine, even with 8 to 10 lamps, was liable to flash in such a way as to render the lighting unsatisfactory and disagreeable. The air blast, however, cured all this, and it was eventually found entirely practicable to operate machines with a single commutator with as many as 50 to 60 arc lamps, and such a commutator could be covered with dirty oil without in any way affecting this operation.



Circuits of Thomson-Houston Arc Lighting System

A description of the electrical measuring instruments, material available for manufacturing, etc., may help to form some conception of the conditions surrounding the early workers at this time, about 1881 and 1882.

As I remember, the volt and the ohm were the only electrical units established and in use. The Paris Congress which met in September, 1881, adopted the C.G.S. system, and confirmed the names and application of "volt" and "ohm." They gave the name of "ampere" to the unit of current which had been previously known as the "Weber," and also recommended the use of the terms "coulomb" and "farad." The term "watt" had not then been introduced.

The ampere meter was not generally made until some time in 1882 or 1883. However, Prof. Thomson recognized the importance of adopting and maintaining a scientific standard; he therefore constructed an instrument on the lines of the "Deprez" galvanometer and spent considerable time in carefully calibrating it by the silver and copper voltmeter method.

This old galvanometer was in use for many years and was calibrated from time to time and found to maintain its accuracy to an extraordinary degree. Every machine that was tested was adjusted by it.

Our first standard of resistance was a 10-ohm coil, which was a copy made by Prof. Thomson of a resistance coil made by Elliot Bros., of London, who at that time were the recognized manufacturers of such standards.

Using this standard 10-ohm coil as a basis, other coils, 1, 2, 3, 5 ohms, etc., were made and used as a Wheatstone bridge for measuring resistances. The necessary astatic galvanometer and a sliding scale Wheatstone bridge of the wire type were also made, and these instruments were used to make the necessary measurements of the armature coils, field coils, arc lamp magnet coils, etc.

The insulating materials which were first used in the construction of dynamos and arc lamps were: canvas soaked in paraffine; and red paper similar to that which is still used, shellacked to keep out moisture. We soon found that this material was not sufficient for the larger machines, and adopted a composite insulation, made of shellacked mica and red paper, which was a prototype of the present composite mica insulation.

The copper wire was covered with cotton thread as at the present time; it was not, however, of such uniform quality, and double cotton covered wire was not common for several years.

Our transmission circuits up to 1882 were bare copper wire of either 6 or 4 B. & S. It was customary to fasten these copper wires to partitions and rafters by means of ordinary iron staples; it was considered quite an advance when porcelain insulators were employed, and a real extravagance when covered wire was first suggested for interior circuits. This suggestion first came from the Fire Underwriters, and the name "Underwriters Wire" was given to this product. It was a long time before covered wire was adopted for outdoor use, and the only insulator known for outdoor service was the common glass telegraph insulator.

We were greatly hampered by the inability to obtain long lengths of cotton-covered copper wire; this necessitated making quite a number of joints in our armatures and in the field coils of even moderate size machines. Of course, wires of special shape, such as flat or square, were absolutely unknown.

There was nothing to be had in the way of porcelain insulating material or special moulded compounds, paraffine and shellacked woods being used for many purposes, and boxwood being especially valuable. Hard rubber could be had only in the form of sheet and tubes, and carbons were so crooked as to necessitate sorting, and a special method of grinding to minimize the effect of the crook.

A cheap and tough substitute for hard rubber was finally discovered in leatheroid, which was one of the earliest insulators of this type to be employed.

The manufacture of arc lamps was confined to one size and character: the so-called 2000 c.p. arc lamp consuming 10 amperes and 45 volts at the arc. Arc lamps of smaller c.p., consuming 6.6 amperes were not introduced until some time in 1884 or 1885.

Even in these early days the question of efficiency and guarantees was considered of vital importance, and every attempt was made to ascertain the efficiencies of our dynamos, with a view to determining the amount of power per standard arc lamp. One of the first and most important instruments erected in our testing room at New Britain was a large transmission dynamometer,—large for those days—capable of measuring the power transmitted to our largest machine, one of 16 to 20 lights capacity. Every machine which was constructed during the first few years was tested on this transmission dynamometer, the current being kept constant by means of the galvanometer already mentioned; the arcs were adjusted to a uniform length and presumably consumed on the average a fairly uniform voltage. Our efficiency tests were probably not greatly in error.

While it was extremely difficult with the meagre measuring devices at our disposal to obtain exact quantitative electrical measurements, there was no lack of appreciation of the necessity for such measurements nor of a desire to obtain them. According to my recollection, much was known in a qualitative manner which was confirmed in later years by exact quantitative measurements. To illustrate, in 1880, and possibly earlier, Prof. Thomson thoroughly understood the general principles controlling the flow and distribution of magnetism in a magnetic circuit, the approximate relation of the permeability of cast iron and wrought iron, the general shape of the saturation curve, etc. In fact, when, a few years later, Dr. John Hopkinson wrote his classic paper on the predetermination of the characteristics of the dynamo electric machine, the principles there enunciated were thoroughly appreciated and recognized as familiar. It was well known that the e.m.f. in a dynamo was proportionate to the speed, the number of turns, the amount of magnetic flux, etc.

The necessity for proper ventilation of the armature was recognized in early designs, and constants had been worked out as to the surface required for the radiation of heat produced in stationary coils.

It was clearly recognized that the iron core of the armature which was subjected to alternating magnetic flux required sub-division for the purpose of insulating against Foucault or eddy currents. To this end the armature core of the Thomson-Houston machine was made of iron wire wound upon a skeleton support, this skeleton being carefully insulated for the same purpose.

Weston was probably the first one in this country to regularly employ a laminated sheet iron armature, the armatures of his arc machines having this construction.

For a number of years Brush used a cast iron armature which was slit in such a direction as to reduce the eddy currents. Of course, this armature was subject to heavy hysteresis losses, but the eddy currents were kept down by the high specific resistance, and it had the merit of cheapness. Prof. Thomson, however, always considered that the cast iron armature was the poorest and most inefficient feature of the Brush design; it was eventually replaced by a sheet iron structure.

In these modern days, the fundamental characteristics of a series constant current dynamo are well understood, and it is known that such a machine must have a characteristic which is practically vertical; *i.e.*, the current must be maintained constant over a wide range of the resistance of the external circuit. For example, a machine which is capable of sending a current of 10 amperes through a resistance of 100 ohms must not send appreciably more than 10 amperes when the resistance of the circuit is reduced to 10 ohms. This can only be accomplished by having the e.m.f. vary in proportion to the resistance; a requirement in a constant current machine which was not clearly understood 25 or 30 years ago except by a very few. Prof. Thomson's machine was so designed that it had, inherently, a nearly vertical "characteristic curve" which could be rendered entirely vertical by the action of the automatic regulator. Brush obtained the same results, over a limited range, by a regulator which shunted his field. These characteristics were necessary not only to enable the load to be changed, but in order to operate with stability. Of course, if such a machine were to operate through a dead resistance, or through a resistance with a positive co-efficient, there would be no danger of instability. The electric arc, however, can be considered an unstable electrical resistance; the resistance of the arc itself being an inverse function of the current, decreasing as the current increases. For this reason, an arc cannot be operated across a constant potential multiple arc circuit but requires the interposition in series with it of a resistance having a positive co-efficient, in which the e.m.f. consumed by the resistance increases with the current rather than diminishes. In the early days arc lights were the only devices placed in the circuit of the dynamo and constituted from 85 to 90 per cent. of the total resistance of the external circuit. It was essential, therefore, that the machine should have such a characteristic that a decrease in the resistance of the circuit would not cause an increase in the current, or at least in the e.m.f. produced at the terminals of the machine; for in this case the current would increase and lengthen the arcs, and in doing so would increase the resistance so rapidly that the e.m.f. would fall—with the result that voltage and current supplied by the machine would go through a series of oscillations. This phenomena was called by Prof. Thomson "hunting," and was simply an unstable phenomena which if uncontrolled rendered the proper operation of an arc light circuit impossible.

Prof. Thomson recognized that an arc machine should have the characteristic which I have mentioned, and which he appropriately called a "drooping" characteristic or a limited h.p. capacity. He stated that this characteristic could be obtained by a saturation of the magnetic circuit and by having the armature sufficiently powerful with respect to the field; in other words, what we would recognize at the present time as a relatively weak field and over-powering armature reaction. While we now know that this machine should have this characteristic, in those days, as I have said, it was not generally so understood, and as a result, many designers who endeavored to produce satisfactory arc light machines failed in their attempts. Furthermore, those machines which did possess this admirable characteristic, such as the Thomson-Houston and Brush, were severely criticised, particularly by mathematicians and electrical writers, as being inefficient and unreliable, the early critics missing entirely the object for which they were designed.

SKIN EFFECT

PART I

BY W. E. MILLER

Introduction

The effect of current alternations on the resistance, self-induction and distribution of current in conductors, apparently has been worked out, except for the increased resistance that results, only as far as the mathematical formulae. This article investigates the conclusions which can be derived from the consideration of these formulae.

Skin effect was first taken up by Lord Kelvin, and his calculations were given to the engineering world in his presidential address to the English Institution of Electrical Engineers in 1889, in which tables were given from which the increase of resistance with size of conductor, frequency, conductivity or permeability could be obtained. Lord Raleigh has also derived the same formulae starting from a different standpoint.

Limiting Conditions

These formulae can be readily applied to calculate the self-induction, resistance, or current distribution in cylindrical conductors; but they do not take into account the effect of other adjacent conductors carrying current. The conductor is regarded as existing by itself. Hence the results obtained from the consideration of the equations do not strictly possess real physical meaning. In certain cases, however, they sufficiently approximate to the real conditions to be of some practical use. In any case, they give an insight into the phenomena which actually occur when all the physical conditions are included; besides forming an aid for estimating the probable real values. Another limitation is that only cylindrical conductors are considered, but here also the results calculated suggest those which obtain with other shapes of conductors. It does not, therefore, seem a waste of time to work out the values of these effects in some detail.

Applications

Possibly a few years ago the question, "does skin effect enter into any engineering problem?" would have been answered in the negative. Since the advent of the alternating current railway system, however, the conductance of the rails as a return circuit has become a vital question, and tests have been made to discover how much the resistance increased due to the alternations of the current. Results of these tests were published, and it was demonstrated that the resistance of the rail return, even at 25 cycles, depended on the superficial area of the surface of the rail and not on its sectional area. The theoretical discussion of this problem is exceedingly complicated, not only because the permeability of iron is far from constant, but also because of the irregular outline of the rail. Hence theoretical formulae were beside the mark. The tests, however, show that the effects foreshadowed by general theoretical considerations, and the actual values of the effects, were in quantitative agreement.

Another problem into which these phenomena enter is the conduction of the heavy currents required for the large alternating current electric furnaces, which will probably be used more and more in the future. Although the distance between the furnace and source of supply is made as short as possible, the currents (in some cases more than 20,000 amperes) are so large that a subdivision of the conductors is necessary, in order to use the conducting material to the best advantage and reduce its resistance to the minimum. The relative position of the conductors has also to be considered, in order to prevent them from shielding one another. Mixing the phases reduces this effect and at the same time minimizes the reactance of the circuit, a matter of generally greater importance than the increase of resistance due to the unequal distribution of current in the conductors. In such cases, the effect of conductor on conductor is large, and therefore the current concentration greater over certain parts of the conductor than over others; that is, the distribution of current will not be symmetrical about the axis of either conductor. Hence the calculations and results as formulated in this article, cannot be applied accurately to this problem, and can merely be used as a guide in estimating the alteration of resistance and reactance.

The earth return for lightning arresters, which has to conduct currents, with but small ohmic drop, at frequencies varying from 10,000 to 1,000,000 per second, can be cited as another case in which skin effect is important. Here the return circuit may be considered as at sufficient distance for it to be neglected, and therefore direct application of the formulae will give fairly accurate results. Skin effect is also a consideration in all instruments which have to measure high frequency disturbances such as are employed in wireless telegraphy or telephony. Enough has been said, however, to show that the matter does not owe its interest entirely to the theoretical side, but possesses a practical application for engineers today.

It is believed that a clear enough idea can be obtained from considering the phenomena in the ideal case, to form the starting point for a further investigation of the more general problem in which the effect of other conductors carrying current is considered. It is hoped, therefore, that someone will be found who will attack this question. It may be mentioned that the general equations of this problem have been given in Maxwell's treatise, but their application is beyond the reach of the majority of engineers without further aid from the mathematical physicist.

Conceptual Analogy

Many analogies have been presented to elucidate the physics involved in these phenomena. Though a mechanical concept, the one given by Oliver Heavyside seems the best. Consider a cylindrical hollow pipe filled with a more or less viscous fluid, and imagine that the rotation of the pipe about its axis represents electromotive force applied at the surface of an electrical conductor, symbolized by the fluid inside the pipe; that is to say, the rotational displacement of the pipe is a measure of the value of the electromotive force at that instant. Suppose now that the pipe is rotated through a given angle with angular speed proportional to a sine function of the time, that is, harmonically, the motion reversing at regular intervals of time. Such a sequence will then represent a sine wave of electromotive force, of which the value at each point of the periphery of the conductor is the same at a given instant. Now follow the sequence of phenomena which occur through the liquid, that is, through the conductor in the electrical problem.

The viscosity of the liquid is the mechanical analogue for the electrical resistance, and the mass per unit volume of the liquid is the analogue for the electric inertia—the self-induction of the conductor. Thus a very highly viscous fluid like syrup represents a conductor of high specific resistance, lead, for example; a fluid of small viscosity, like water, representing a conductor of high conductivity, copper for example. A heavy fluid like mercury represents a conductor of high magnetic permeability, iron, for example; and a light fluid, one that has permeability unity. Due to the viscosity, the motion of the pipe will transmit a wave motion through the liquid, the displacement at any point being proportional to the current density at that point. The amount and phase of this displacement, a short interval of time after the initial peripheral impulse has been given, obviously depend on the viscosity of the fluid.

This will be readily seen by taking two limiting cases. If the fluid does not possess viscosity, its several parts have no effect on one another; hence the displacement will be confined to the skin in contact with the pipe and will never penetrate further. If, on the other hand, the viscosity is infinite, or, which amounts to the same thing, each portion of the fluid is rigidly connected to every other portion, that is, the fluid is solidified, the displacement will be propagated instantaneously through all parts, and will reach its appropriate value at each point at the same moment of time. Here the analogy must not be pushed too far or it will lead to results physically impossible, electrically speaking.

The first case corresponds to infinite conductivity, and the second case to no conductivity, that is, to an insulator. Since in the latter case, however, the mass moved at each instant must be taken as the whole mass—the parts being rigidly connected together—the displacement would be exceedingly small; and since there is no relative motion of one part over another, no frictional loss results. Electrically speaking, this means that the displacement current in an insulator is small and the energy loss zero. It also shows that, for high resistance material, the current density in any given cylindrical surface inside the conductor has more nearly the value of that existing at a given moment in the surface layer, than would be the case in conductors of higher conductivity; in other words, the penetration is greater and the phase lag between the currents in the various cylindrical surfaces smaller.

A relative displacement, and therefore frictional loss, exists between successive layers of the liquid due to viscosity, that is, due to resistance in an electrical conductor; hence, an energy loss I^2R results. For this reason *the wave of displacement takes time to travel through the liquid;* so that the current density does not reach its maximum value at each point of the conductor at the same moment. Hence there is a phase lag between currents in successive layers through the conductor as well *as a continuous reduction in intensity of current density*, the change of which is most rapid at the periphery. If the conductance, diameter, frequency, or permeability is sufficiently great, the current at a given depth may have attained its maximum value when the current at the periphery has reversed and reached its maximum in the opposite direction. In fact, at certain definite depths, currents may be flowing in direct opposition; deeper again, in phase with that flowing in the outermost layer, and so on, as the center of the conductor is more nearly approached. Phase displacements, and also the ratio of maximum current densities between periphery and center, can have any values however large, depending on the magnitude of the circuit constants given above.

If the specific gravity of the fluid is high, it is clear that only a small displacement will be produced for a given rotation around the periphery, and the time lag will increase with the mass per unit volume of the fluid. The displacements at various depths through the fluid will be less for a given alternating rotation at the periphery than for a fluid of smaller density. Electrically speaking, this means that conductors of large magnetic inertia will possess a larger phase displacement, and that the current density in each layer will not only be smaller, but will fall off more rapidly in intensity from the surface towards the center than will be the case in conductors of smaller magnetic permeability, other things being equal.

Amount of Conductor Affected

Hence, as the frequency or conductivity increases, so will the current be more and more confined to the outermost layer; the penetration will be small. Also in large conductors, the current will practically all flow in the outer zone of the conductor, the depth of which depends on the frequency, conductivity and permeability. Thus it follows, that for each type of conductor at a given frequency there is a critical diameter beyond which current penetration is practically constant. In other words, in large conductors the inside core carries no current; it can therefore be removed without altering either the current distribution or the ohmic resistance of the conductor. Skin effect depends on the square root of the three factors, frequency, specific conductivity and permeability, and directly on diameter. Hence, for conductors made of iron, the permeability of which can be conservatively estimated at 300, skin effect is very noticeable, and even small conductors at moderate frequencies will show a considerable increase of resistance.

High Conductivity Versus Low

As illustrating the effect of very high conductivity, it may be of interest to note the following:—

Suppose a material were discovered of which the conductivity was thirty times greater than that of copper. Then, due to skin effect, the resistance of such a conductor one inch in diameter, at 25 cycles, would be about 3¼ times the resistance of the conductor with uniform distribution of current. Hence, the resistance of this conductor, instead of being $\frac{1}{30}$ of the resistance of a copper conductor of the same diameter, would be approximately $\frac{1}{9}$ the resistance. If, however, the diameter were reduced so as to obtain the same I^2R loss in both cases, the diameter of the high conducting material would be so small that skin effect would be negligible, its effective resistance would not be increased, and the saving in material would therefore be exactly proportional to the increase in conductivity. It is, in fact, true that no matter what the specific resistance of conductors may be, skin effect produces the same increase of resistance, provided the diameters of the conductors are so proportioned as to give equal conductivity in each case. Hence, so far as skin effect is concerned, no advantage is gained by choosing one material rather than another, provided the permeabilities are equal in all cases.

Variation of Resistance and Self-Induction

When the frequency is very low, the displacement wave has time to reach the center and the proper displacement to be fully generated in each layer before the electromotive force has greatly changed; that is, the currents at every point in the conductor are always practically in synchronism with one another and of equal intensity; uniform current density obtains throughout. This is, of course, the condition giving minimum energy loss, each part of the conductor being utilized to the fullest advantage. Any action, therefore, which alters this distribution increases the loss, and consequently the resistance to a given current; resistance being here defined as: $\frac{\text{heating}}{\text{current squared}}$. Constant instantaneous current density throughout the conductor—which theoretically occurs only in constant current circuits—means maximum self-induction inside the conductor, due to its own current alone; hence, any alteration of the distribution means a reduction of self-induction. The specific resistance and self-induction may indeed be regarded as two opposing forces; the former tries to keep the distribution of current constant throughout the conductor, the latter to drive the current to the surface. The actual distribution at any moment is due to the resultant effect of these two conflicting forces.

Equations

Lord Kelvin has shown that the current density in any layer is related to the current density at the center of a cylindrical conductor (all quantities being expressed in the centimetre, gram, second system), as follows:

$$s_r = s_c\ (ber\ q\ cos\ pt - bei\ q\ sin\ pt) \quad (1)$$

Where s_r and s_c are the current densities at radius r and at the center respectively, $p = 2\pi n$, t the time in seconds, n the frequency in cycles per second, and $ber\ q$, $bei\ q$, the following functions of q:

$$ber\ q = 1 - \frac{q^4}{2^2 4^2} + \frac{q^8}{2^2.4^2.6^2.8^2} - $$

$$bei\ q = \frac{q^2}{2^2} - \frac{q^6}{2^2.4^2.6^2} + $$

$$q = 2\pi r\sqrt{2k\mu n}$$

k is the specific conductivity, μ the permeability.

Meaning of q

The quantity q enters into all the formulæ, and its meaning should therefore be appreciated in order to be able to interpret properly the equations that follow. As already stated,

$$q = 2\pi r\sqrt{2k\mu n} = 8.86 r\sqrt{\mu k n}$$

The value r is given in centimetres, and the other quantities as stated above. The value of k for copper can be taken as $\frac{1}{1620}$; μ, except for magnetic substances, is always unity.

If the values of the quantities on which q depends, namely, the conductivity, permeability, frequency or radius, are so altered as not to affect its value, the numerical results obtained from the solution of the equations will be unaltered. For example, if the frequency be quadrupled and the diameter of a conductor be halved, so that its value in terms of q is the same, the resistance, self-induction, current distribution, and lag of currents at different depths, will have the same values as those that obtain with the larger conductor at the lower frequency. That is to say, the values of the variables n, k or μ are interchangeable amongst themselves, or with the square root of r.

It is for this reason that all the curves have been plotted with abscissæ in terms of q. By so doing the curves do not lose generality, but can be applied directly to any definite case using conductor diameters, frequencies, permeabilities, or conductivities such that when these values are substituted in the q equation, its value does not become greater than the

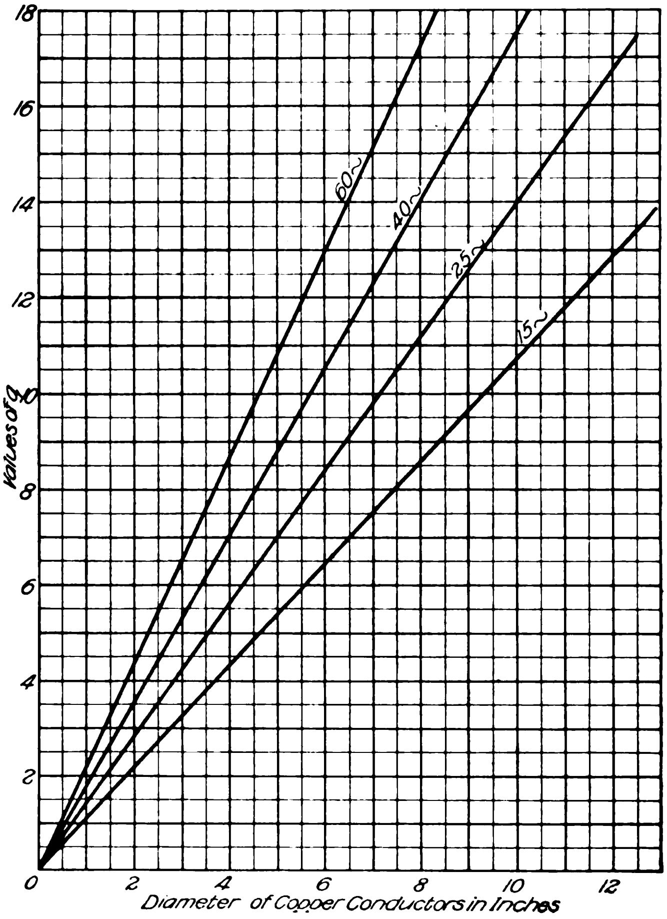


Fig. 1

largest value of q given in the curves. Since most problems of practical interest deal with either copper or aluminum conductors, at frequencies of 25, 40 or 60 cycles, the curves Figs. 1 and 2 have been drawn, which connect the values of q at these frequencies with the diameter in inches of conductors made of these two materials. Any other value of q corresponding to a frequency or conductor diameter larger than those included in the curves can, of course, be readily obtained from the formula.

In calculating these curves, the specific resistance of aluminium has been taken as 1.78 times that of copper. That is to say,

$$k = \frac{1}{2900}.$$

Current Density and Total Current Formulae

Formula (1) can be expressed in the following form:

$$s_r = s_c\sqrt{ber^2q + bei^2q}\ cos\left[pt + tan^{-1}\frac{bei\ q}{ber\ q}\right] \quad (2)$$

where the angle of lag ϕ between currents in different layers is: $\phi = tan^{-1}\dfrac{bei\ q}{ber\ q}$ (3)

Equation (2) shows that the maximum current densities attained at each point of the conductor, are equal to s_c the current density at the center, multiplied by $\sqrt{ber^2q + bei^2q}$ when s_c is at its maximum value, q involving the radius of the layer in question.

The total current in the conductor at epoch pt is $I\ sin\ pt = 2\pi s_c\left(\int_0^r r\ ber\ q\ cos\ pt\ dr - \int_0^r r\ bei\ q\ sin\ pt\ dr\right)$

Since $\dfrac{dq}{dr} = 2\pi\sqrt{2k\mu n}$, this equals $\dfrac{s_c}{4\pi\mu kn}\left(ber_1q\ cos\ pt - bei_1q\ sin\ pt\right)$

where $ber_1q = \int_0^q ber\ q\ dq$, and $bei_1q = \int_0^q bei\ q\ dq$

Hence $I\ sin\ pt = \dfrac{s_c}{4\pi\mu kn}\sqrt{ber_1{}^2q + bei_1{}^2q}$

$$\times cos\left[pt + tan^{-1}\frac{bei_1\ q}{ber_1\ q}\right] \quad (4)$$

Hence the instantaneous total current is a maximum when $pt = - tan^{-1}\dfrac{bei_1\ q}{ber_1\ q}$ and zero when $pt = \dfrac{\pi}{2} - tan^{-1}\dfrac{bei_1\ q}{ber_1\ q}$

The total current (root mean square) with uniform distribution $= \dfrac{2\pi s}{\sqrt{2}}\int_0^r rdr = \dfrac{\pi r^2 s}{\sqrt{2}}$, where s is the maximum current density. The total current, when skin effect is taken into account, has a root mean square value which is:

$$I = \frac{s_c r^2\sqrt{2\pi}}{q}\sqrt{ber'^2q + bei'^2q}\ . \quad (5)$$

where $ber'q$ and $bei'q$ are: $\dfrac{d\ ber\ q}{dq}$ and $\dfrac{d\ bei\ q}{dq}$ respectively. Hence the ratio of current density at the center of the conductor, to the current density that obtains with uniform distribution for equal total current, is:

$$\frac{s_c}{s} = \frac{q}{2\sqrt{ber'^2q + bei'^2q}}\ . \ . \ . \quad (6)$$

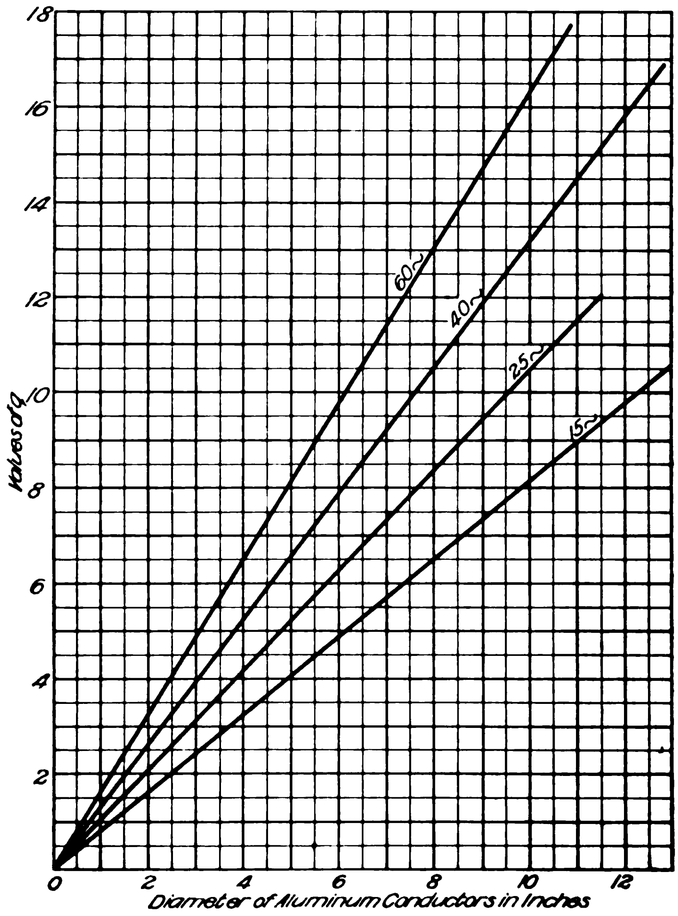


Fig. 2

and the ratio of the current density at the surface s_s to the current density with uniform distribution, is:

$$\frac{s_s}{s} = \frac{q\sqrt{ber^2 q + bei^2 q}}{2\sqrt{ber'^2 q + bei'^2 q}} \quad . \ . \ . \ . \qquad (7)$$

The functions $ber_1\, q$ and $bei_1\, q$ have been calculated for the values $q = 3$ and $q = 8$. By the aid of formulæ 2, 4 and 5, the curves, Figs. 3 and 4, have been drawn giving the instantaneous currents in the various layers of a conductor of which the diameter is represented by $q = 3$, and of one of which the diameter is represented by $q = 8$. Four epochs have been chosen as illustrating those most typical in the complete cycle, namely, when the current density at the surface is a maximum and zero respectively, and when the total current in the conductor is a maximum and when it is zero. Similar curves obtain, of course, at epochs differing by 180° from those plotted.

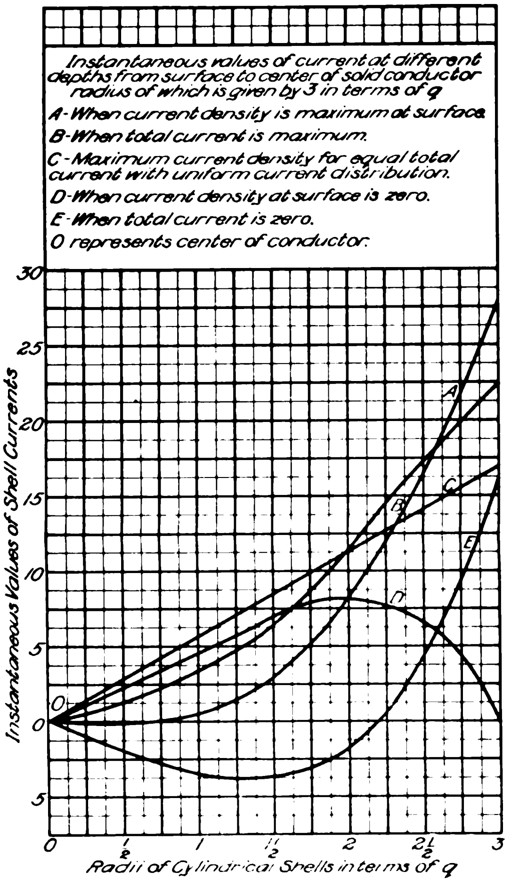


Fig. 3

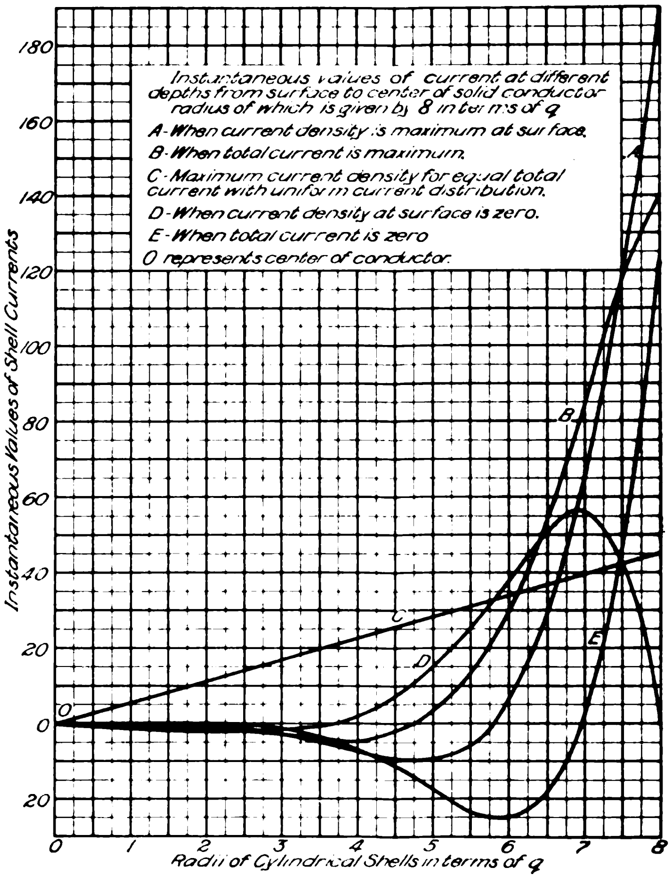


Fig. 4

It will be noticed that the current density at the surface is not a maximum when the total current is a maximum, and that it has quite a large value when the total current is zero.

The areas included in the straight lines drawn on these diagrams are equal to the total current at its maximum in the conductor with uniform distribution (constant instantaneous current density). Hence, this area is equal to the area included by the two curves marked B in the two diagrams, respectively. The areas of the curves representing the instantaneous currents in each layer of the conductor when the total current is a maximum are therefore equal to the total current, in the uniform distribution case, when it is at its maximum.

From equation (7) the current density at the surface or in any layer can be readily obtained at any epoch, in terms of the current density corresponding to a total current with uniform distribution of equal root mean square value. To facilitate these calculations and to show the values of the ratio of the current densities obtained, curves Fig. 5 have been prepared. They give the ratios of the maximum current density at the surface and center respectively, to the current density that obtains for a total current of equal root mean square value with uniform distribution, in conductors corresponding to values of q up to $q = 16$. It will be noted that curve A becomes practically straight for values of q greater than 4, in fact, the ratio $\dfrac{\sqrt{ber^2\, q + bei^2\, q}}{\sqrt{ber'^2 q + bei'^2 q}}$ is practically unity for large values of q; and the limiting value of the ratio of the surface current density with skin effect, to the current density with uniform distribution, is $\dfrac{q}{2}$. The value of the current density at the center becomes vanishingly small for large values of q, as shown on the other curve. Hence, the current densities at the center of conductors of which the radii are represented by large values of q, bear a very small ratio to the average current density through the whole conductor.

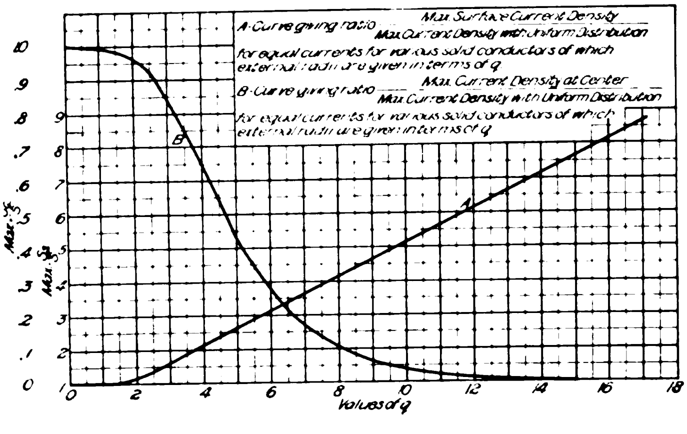


Fig. 5

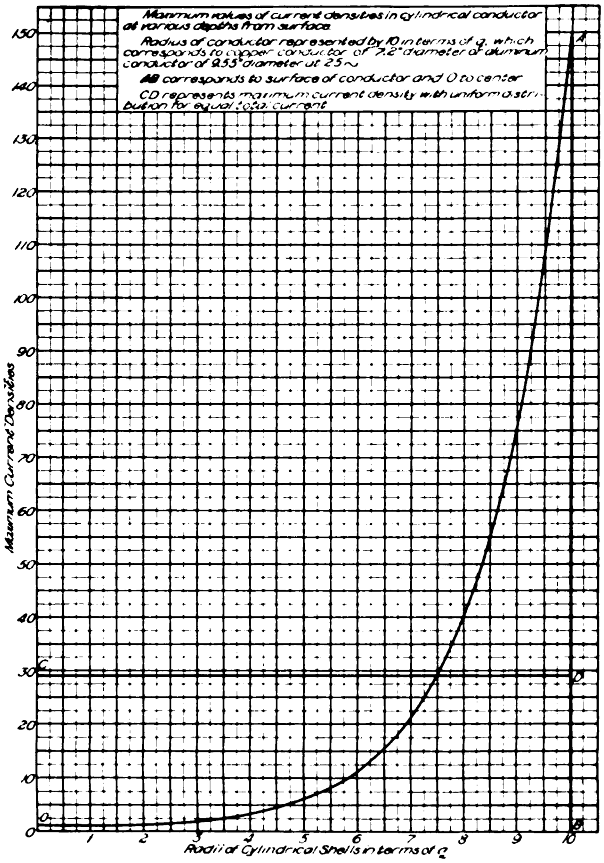


Fig. 6

Curve Fig. 6 shows the maximum current densities attained at various depths in a cylindrical conductor for $q = 10$. These maxima, of course, do not occur simultaneously, and the curve is drawn without reference to the phase differences existing between the currents at various depths. It will be seen that in this case, the maximum current density at the surface is 150 times the maximum current density that is attained at the center of the conductor. The line CD parallel to the abscissæ, represents the maximum current density with uniform distribution, for a root mean square total current equal to a current corresponding to the current densities given in the curve. The two curves well show how great a difference exists between the current density distribution in the two cases.

(To be Continued)

ECONOMY TESTS OF HIGH SPEED ENGINES

ABSTRACTED BY RICHARD H. RICE

At the June, 1908, meeting of the American Society of Mechanical Engineers, held at Detroit, an interesting paper was presented by Messrs. F. W. Dean of Boston and A. C. Wood of Philadelphia, on the subject: "Economy Tests of High Speed Engines". During the year 1907 the authors conducted economy tests on eight high speed engines, seven of which operated non-condensing, and one operated condensing. These engines were tested in the conditions in which they were found operating in the several power stations, care being taken to do nothing that would improve their efficiency, the object of the tests being to determine what may be expected of such engines in actual service—engines that have been given the ordinary care which such power stations permit.

The engines tested were as follows:—

Engine No. 1. 15 in. by 14 in. by 240 r.p.m. horizontal single flat valve engine with a 100 kw. d.c. generator on the shaft.

Engine No. 2. 16 in. by 15 in. by 240 r.p.m. vertical single flat valve engine with two 50 kw. d.c. generators on the shaft.

Engine No. 3. 14 in. by 12 in. by 300 r.p.m. horizontal single flat valve engine with two 40 kw. D.C. generators on the shaft.

Engine No. 4. 16 in. by 14 in. by 270 r.p.m. horizontal engine with four flat valves, and having a 125 kw. A.C. generator on the shaft.

Engine No. 5. 12 in. and 19 in. by 14 in. by 230 r.p.m. vertical cross compound condensing piston valve engine with a 100 kw. D.C. generator on the shaft.

Engine "A." 18 in. by 18 in. by 220 r.p.m. horizontal single piston valve engine with a 150 kw. D.C. generator on the shaft.

Engine "B." 15 in. by 16 in. by 250 r.p.m. horizontal single piston valve engine with a 100 kw. D.C. generator on the shaft.

Engine "C." 12 in. by 18 in. by 190 r.p.m. horizontal engine with two flat inlet valves and two Corliss exhaust valves, and having a 75 kw. D.C. generator on the shaft.

The tests were made with the greatest care, and a full description of the method of the tests and of the engines and results obtained will be found in the Transactions of the A. S. M. E.

The results of the tests are summarized by the authors as follows:

COMMENTS

"The table (page 171) shows the economical results of the tests of the non-condensing engines:

"There are several striking features in these results, as follows:

"*a* The most important is that the four valve engines, which were built to be more economical than single valve engines, have utterly failed in their object. No. 4 engine had steam superheated some 20 deg. fahr., and this gave the engine a great advantage over any other tested. These results show that efforts to realize economy by duplication, or multiplication, of parts, even if ports are shortened and clearances reduced, accomplish nothing. The duplication of valves used in both four valve engines simply increased the opportunity for leakage. In engine C, the exhaust valves probably were tight, and as far as possible minimized the effect of the probable very large leakage by the inlet valves.

"After considering these tests, we do not hesitate to advise builders to abandon four valves for high speed engines unless they are prepared to build a really high class engine having four Corliss or gridiron valves, made and fitted in the best manner. Even then it would be necessary for them to prove their case. Steam engines of whatever type should have valves that are not only tight originally, but that should become so by wear if they are not so originally. The wearing process should be a tightening process.

"*b* Comparing the results of the flat valve engines, the most economical results were obtained from engine No. 3, which had a valve which automatically takes up wear, and if it does not cut, must maintain itself tight for long periods. The valve of this engine is evidently its saving feature, for the port system could hardly be worse for realizing economy. The ports are long and tortuous, have great surface, and the clearance volume must be large.

"*c* Comparing the piston valve engines, there is little reason for one being superior to the other, although engine A surpassed engine B in economy. Engine B has considerable unprotected surface on the steam chest, and this must increase condensation.

"*d* Comparing the flat and piston valve engines: if we do not consider the loads, the most economical result was obtained from a piston valve engine. This result was, however, obtained when the engine was heavily loaded. With the lighter loads that are comparable, the flat valve engine No. 3 surpassed engine A in economy. Moreover, the flat valve engines give a flatter load curve than the piston valve engines, which is a valuable feature.

"*e* The performances of the perfectly balanced flat valve engines are so relatively poor, that it seems to disqualify them, unless this type of valve can be made with some mechanism by which wear will not increase leakage. Possibly metal strips might be used in a manner similar to that employed in the Richardson valve. It must be difficult to keep a shop force up to the pitch required to fit these valves, balance plates, and distance strips properly. It is doubtful, in fact, if this type of valve is tight even when new, and it has no chance of ever being tight thereafter unless it is re-fitted, which is seldom done. This type of valve must take the whole responsibility of the extravagance of the four valve engines. Engine No. 1 had the advantage of steam superheated 7 deg. fahr. to 14 deg. fahr.

"*f* The results show that heavy loads with high speed engines give the most economical results, and this confirms the statement of D. K. Clark in the early fifties that the most economical point of cut-off in locomotives is at about one-third stroke. This was again substantiated by Professor Goss with the experimental locomotive at Purdue University.

"*g* One interesting thing about the results is that no stationary high speed engine is as economical as passenger locomotives that are in good order. We expect such locomotives to use as little as 26 lb. of steam per indicated horse-power per hour, and better results have been obtained. This economy was realized before very high steam pressures were used.

"*h* It is unfortunate that the tests were not of greater duration, but the results would probably not have been materially different. Moreover, the results accord very well with what might be anticipated. The difficulty of making the tests at all, and the importance of obtaining the results as soon as possible are the excuses for the shortness of the tests. It should be stated, however, that some of the tests were of greater durations than given; namely, those during which permanent rates were established.

"*i* In regard to the relative economies of flat and piston valve engines, I am inclined to believe that the former are the more economical, if the valves are self-adjusting with wear and are of a good design. They must have less port surface and less clearance, and can be made to adjust themselves for more wear than piston valves.

"*j* Persons who are familiar with the guarantees of steam consumption which accompany sales of high speed engines are aware that these guarantees are usually met in shop tests, but the tests described herein show that no engine realized economies which would have been guaranteed. From the results we are justified in thinking that most high speed engines rapidly deteriorate in economy. On the contrary slower running Corliss or gridiron valve engines improve in economy for some time and then maintain the economy for many years. It is difficult to see that the speed is the cause of this, and it must depend on the nature of the valve."

Engine	Duration of Service *Hrs.*	Steam Used per Hour to Atmosphere at					
		¼ Load *Lbs.*	½ Load *Lbs.*	¾ Load *Lbs.*	Full Load *Lbs.*	1¼ Load *Lbs.*	1½ Load *Lbs.*
No. 1—One Flat Valve	15,216		38.5 per i.h.p. 37.2 per i.h.p. 62.3 per kw. hr. 60.2 per kw. hr.	36.2 per i.h.p. 58.4 per kw.			
No. 2—One Flat Valve	20,000		36.7 per i.h.p. 66.0 per kw. hr.		35.8 per i.h.p. 59.7 per kw. hr.		
No. 3—One Flat Valve	28,644		31.7 per i.h.p. 57.1 per kw. hr.		32.0 per i.h.p. 57.4 per kw. hr.		
No. 4—Four Flat Valves . . .	719		39.6 per i.h.p. 59.8 per kw. hr.	37.5 per i.h.p. 54.9 per kw. hr.	36.7 per i.h.p. 54.7 per kw. hr.		
A—One Piston Valve	32,000		39.75 per i.h.p. 61.76 per kw. hr.	34.67 per i.h.p. 51.80 per kw. hr.		29.53 per i.h.p. 43.42 per kw. hr.	
B—One Piston Valve	5,600	52.0 per i.h.p. 96.7 per kw. hr.	40.7 per i.h.p. 64.8 per kw. hr.	36.3 per i.h.p. 55.2 per kw. hr.	33.55 per i.h.p. 49.4 per kw. hr.		
C—Two Flat Inlet Valves, Two Rotating Exhaust Valves . . .	10,800		44.02 per i.h.p. 79.30 per kw. hr.		36.7 per i.h.p. 60.48 per kw. hr.		34.10 per i.h.p. 53.74 per kw. hr.

The discussion which followed was interesting, although much of it did not follow the lines of the paper. A summary is given of those portions that apply to the results of the tests. Full discussion will, of course, be found in the A. S. M. E. Transactions.

Mr. George H. Barrus said that the striking thing which these tests show is that unpacked piston valves, or balanced valves which do not automatically take up wear, often leak so much in ordinary service that engines equipped with them are most wasteful steam users. He thinks that engineers generally who have had occasion to test such engines fully realize this fact.

Mr. Barrus went on to say that it would add much to the interest of the paper to include in the list one or more engines having single piston valves with ring packing, where the wear is automatically provided for by means of the flexible ring. In closing, Mr. Dean stated that he understood that the engines lettered "A", "B" and "C" in the test results have this type of valve.

Mr. C. A. Dawley spoke in part as follows:

> "The tests reported by Messrs. Dean and Wood are of much interest to steam users, when considered as a collection of isolated tests on automatic engines under various conditions of type, size, speed, load, steam pressure, steam quality, back pressure, over-rating and under-rating. They should be of value as an indication of what results are being obtained with steam in the operation of these individual engines."
>
> "The rather poor results obtained in most of these tests are attributed by the authors chiefly to valve leakage. There is another factor, not touched upon, which may be equally important; *viz.*, piston leakage. This is usually assumed to be small, chiefly because, on account of condensation and other uncertain elements, there is no reliable way of determining its extent."

The tests reported by Messrs. Dean and Wood in this paper are extremely interesting, as showing the actual performance of engines in service in the power stations of users, receiving the ordinary care which such power stations provide. Tests of this nature are very difficult to obtain, because they involve tests of the boiler plant as well as of the engines, and considerable changes must be made in the arrangement of the station to permit of these tests being made with accuracy. There is also difficulty because of the commercial requirements of the customer, which always interfere to a great, and usually to a prohibitive extent.

The tests indicate conclusively that the refinements of construction which have been considered necessary to secure high economy in high speed non-condensing engines, such as small clearance, prompt valve action, accurate adjustment of the compression, etc., are of no importance whatever when the engine has once been put into service, since the question of leakage is shown to be the all-important element in the efficiency of an engine of this type. All engines containing valves sliding on their seats, whether these valves are piston, plain slide, or balanced valves, one, two or four per cylinder, are shown to be subject to this great source of loss, and therefore, until this difficulty is eliminated, consideration of the minor refinements is unnecessary.

The tests also indicate one of the chief reasons for the superior economy of the compound engine, as compared with the simple engine, which is, that leakage through the high pressure cylinder is all caught in the low pressure cylinder and there utilized. Again, in the low pressure cylinder, the leakage is less in amount and importance, due to the low pressure involved. This point has undoubtedly much to do with the success of this type of engine. Unfortunately, however, the compound engine is not well adapted for non-condensing use, since it requires to be loaded at about the point for which it was designed, otherwise the distribution of work in the two cylinders becomes deranged, and for light loads the low pressure cylinder actually increases the water rate of the engine, as compared with a simple non-condensing machine, due to the formation of loops in the indicator cards and consequent development of negative work in both cylinders. This fact has been proven time and again in practice and on varying loads; for instance, on railway work where the load is particularly variable, several power stations have been entirely remodeled due to the great cost of operating them with non-condensing compound engines.

One significant feature of the results of tests reported is shown by plotting water rate curves of the engines, by which it will be seen that the proportioning of the engine cylinders is in many cases entirely wrong for the generators to which they are attached, and tremendous variation in the adaptability of the engines to their generators is shown, which fact seriously affects the showing made by various engines.

Comparing the engines tested with similar capacities of steam turbines, the water rates obtained in these tests are considerably higher than those obtained from the turbines. It may be objected that the turbine water rates are obtained from machines comparatively new, and that it is not known that turbines will retain their original water rate indefinitely. This contention, is, however, not in accordance with the facts.

A number of tests have been made on turbines which have been in constant operation for from one to two years, and it was shown, within the limits of accuracy of the test methods, that the water rates of these turbines were the same after the completion of the above-mentioned periods of use as at the beginning. Unfortunately, the conditions under which these tests were made were not such as to permit the tests to be properly presented at this time but it is hoped and expected that in the near future a number of tests can be made by independent engineers, which will be of the same high class as those given in this paper by Messrs. Dean and Wood, and which will show the actual performance of turbines of similar capacities after extended periods of use, for comparison with the figures given in this paper.

Comparing the engine with the turbine, we have in the former a number of rubbing surfaces, deterioration of which immediately affects the efficiency of the engine to a serious degree. These rubbing surfaces exist in the valves and seats, and in the piston packings. It is true that these parts are lubricated by well known means, but this lubrication is essentially imperfect, since it depends upon the atomization of the oil in a current of steam and its deposition on the cool surfaces of the valves and cylinders. This process is subject to great variation in its effectiveness, particularly where the steam carries considerable moisture, in which case it is well known that the lubricant becomes rapidly washed off from the surfaces, instead of being left on them to do its proper work. What occurs in the case of considerable moisture is only a well-defined indication of what actually takes place at all times during the operation of the machine, although to a lesser extent, and this irregular and uncertain application of the lubricant occurring continuously, results in the wear which has caused the leakages that have in turn caused the loss of efficiency noted in the engines under discussion.

In the steam turbine we have no parts exposed to the steam which might affect the efficient operation of the machine and which require lubrication; and discussing in particular the Curtis turbine, there are no moving parts affecting steam consumption that come in contact with other parts, either moving or stationary, with the exception of the admission valves. These are of the single-poppet type, and wide experience has shown that they remain tight when once put in that condition. After the steam has once passed into the nozzles, the only parts which can affect steam consumption by deterioration are the nozzles and the revolving and stationary buckets.

In an experience covering many hundreds of turbines, in operation for periods of from 5 years downwards, no cases have come to my notice where nozzles have deteriorated, with but one exception, where by error some improper material was introduced into the nozzles of one stage of a Curtis turbine exposed to the influence of salt water in the steam. In this case the nozzles rapidly deteriorated, but nozzles in the other stages of the same turbine, constructed of the proper material, showed no deterioration whatever.

In some cases, the revolving and stationary buckets, formerly made of steel, showed deterioration after two or three years use, where salt and moisture were present in the steam, and where the turbine was frequently shut down and allowed to stand for a sufficient length of time for rust to form on the surfaces. Present practice with this particular type of turbine is to use bronze buckets, which are not subject to any deterioration so far as experience has demonstrated.

The question of packings needs some discussion, since it might be claimed that in the turbine there are packings which could cause leakage, and this leakage would very likely cause loss of efficiency. Experience shows, however, that the packings of a turbine are fully as reliable and remain fully as tight as those used in ordinary engine practice.

Resume

"Simple non-condensing high speed reciprocating engines in sizes up to 150 kw. capacity are therefore subject to the following causes for loss of efficiency:

(1) Wear of valves and pistons, causing excessive steam leakage.

(2) Loss of efficiency on variable load due to the disturbance of cylinder conditions; this loss is well known to occur when engines are so loaded.

Compound non-condensing high speed engines with steady loads at about the rated capacity are free from the first source of loss above mentioned, but are unsuited for varied loads and are much more expensive.

Steam turbines, while showing a lower steam efficiency under test conditions, maintain their efficiency indefinitely, and also maintain an average efficiency under varying loads equal to the actual test efficiency at the load which is the mean of such variations.

Therefore, for all practical conditions, the non-condensing steam turbine of capacities up to 150 kw. is more efficient, from the standpoint of maintained efficiency, than any form of high speed reciprocating engine."

In addition to those portions of the discussion of Messrs. Dean and Wood's paper already given, the following communications were elicited:

Mr. R. C. Stevens said in part:

"Valves which are non-adjustable for wear, of necessity have two or three thousandths of an inch clearance when new, even if fitted with the highest mechanical skill, and after operation for short periods permit the leakage of much steam into the exhaust without useful work being accomplished thereby."

Mr John C. Parker stated that he has investigated a large number of plants of the type referred to in the tests of Messrs. Dean and Wood, which type is that commonly found in office buildings and light manufacturing plants, and from what he has seen of the ordinary conditions obtaining, believes that one explanation of the failure of small engines to maintain good efficiency lies in the poor oversight provided. This state of affairs is due to the expense of necessary attendance.

Dr. W. F. M. Goss said:

"The results presented by this paper are likely to be received with some surprise by those who have not followed the development of the high speed engine with more than ordinary care. But as a matter of fact, it is probably true that the results reported are not especially exceptional. It would be wrong, however, to draw from them a sweeping conclusion to the effect that the more highly articulated type of engine is no better than the simple type. The paper presents a fragment of the story only; the rest of it should be known before broad interpretations are attempted.

"The conclusion of the paper, that while the more highly articulated types of engines are capable of rendering more efficient service than those of simpler type, they do not do so after being for a time in rough and tumble of service, is not so much an argument against the more highly articulated types, it seems to me, as it is an argument favoring greater attention to the details of their maintenance. The whole question is one which is very common and very old. In most classes of machinery, higher efficiency calls for greater refinement in design, and greater refinement in design demands additional attention, and failure to bestow this additional attention often defeats the whole purpose of the designer."

It might be well to point out that if additional attention is given to such engines, in accordance with Dr. Goss's recommendation, the cost of this additional attention should be added to the cost of producing power, when comparing results with those obtained by the steam turbine, which, of all the motive powers so far discussed, requires the least amount of attention.

Mr. G. A. Young said that he values the results of the tests for two reasons; first, because the opportunity to secure reliable data from different types of the same class of engines is rare; and second, because all the engines there reported were working under normal conditions. The steam consumption is well within the range experience has taught us to expect from high speed engines. Mr. Young then gave results of tests on six engines, as follows:

Engine No. 1: The engine reported on this test was run about five days after installation, before the test was made. It was directly connected to a two stage centrifugal pump and had a piston valve.

1 Number of engine	1	2	3	4	5	6
2 Horizontal or vertical	V	H	H	H	H	H
3 Load on engine	centrifugal pump	fan	brake	generator	lumber mill	brake
4 Time of service	5 days	5 yrs.	10 yrs.	2 mos.	8 mos.	5 yrs.
5 Dimensions of cylinder, in.	10 by 12	8 by 12	7 by 12	13 by 12	16 by 22	7¾ by 15
6 R.p.m.	325.5	250	225	268.6	200	220
7 Steam pres. lb. gage	146.4	140	125	120.3	79.6	140
8 Quality of steam, per cent.	98.4	98.3	99	98.7	97.3	98
9 Back pres. lb. gage	1	2	2	12	4.8	1
10 I.h.p.	69.4	30	28	130	123	45
11 Lb. of steam per i.h.p.h.	46	38	36	34.6	31 7	30.4

Engine No. 2: This engine was five years old and used a plain, unbalanced D valve. It was directly connected to a large fan.

Engine No. 3: The valve on this engine is similar to that on engine No. 1 described by Messrs. Dean and Wood. It has seen 15 years of service.

Engine No. 4: Engine No. 4 was directly connected to a 75 kw. generator. It used one flat valve, working between the seat and a pressure plate, self-adjusting for wear. The engine had been run for two months when the test was made.

Engine No. 5: This engine was fitted with four valves of the rotary type, operated by two eccentrics. The test given was the acceptance test after the engine had been in service about eight months furnishing power for a lumber mill.

Engine No. 6: The valve on this engine is of the piston type, with a riding cut-off valve. The valve chest and cylinder had been renewed five years previous to the test.

All the engines except No. 2 had shaft governors.

All the engines were working at about their normal rating, so that the results given in the table are as good as could be expected. Engine No. 6 shows the best results, Engine No. 5, with the four valves, coming next.

When comparing the steam consumption of these engines with those given in the table of Messrs. Dean and Wood's report, it must be remembered that their results have been reduced to atmospheric conditions, and also that the horse-power of the engines in my table is generally lower

Mr. C. H. Treat gave the results of tests on a small high speed engine with piston valve, of 30 h.p. rating, the results of these tests being here given:

Mr. Dean, in closing the discussion, said that some of the tests which have been mentioned in the discussion were made after the engines were more or less repaired, and therefore do not come within the scope of the paper, which was to discuss tests on engines just as they were found.

The general conclusion which may be fairly drawn from the discussion is that the results are accepted by those who have knowledge and experience in the operation of high speed engines as being correct and not at all surprising, and no adequate and conclusive evidence is submitted that other types of engines with other types of valves would be likely to produce more favorable results.

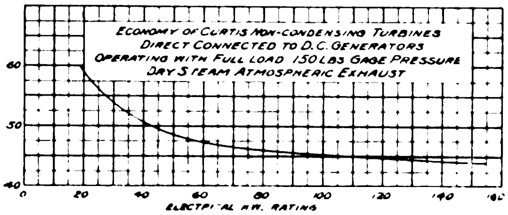


Fig. 1

In addition to the discussion presented by the writer on the subject of steam turbines, it may be of interest to compare a curve (Fig. 1) which fairly well gives the results at full load, these being daily obtained from small turbines. From tests on turbines which have been in operation for extended periods, these results are found to be well maintained.

It will be seen that these results compare very favorably with those obtained from the engines reported by Messrs. Dean and Wood and others who discussed the paper. It is therefore evident that the steam turbine, in its worst and most uneconomical form, that is, in small capacities and operating non-condensing, is fully equal if not superior to similar sizes of steam engines, when these engines are tested under ordinary running conditions, and subject to the usual attention which is possible in plants where such engines are customarily placed.

	Test No. 1	Test No. 2	Test No. 3
Date	July 10, 1908		
Previous length of service	10,000 hrs.		
Size of cylinder	7,082 in. mean diam. by 7 in.		
Diam. of piston rod	$1\frac{3}{16}$ in.		
Engine belted to	Centrifugal fan wheel 30 in. diam.		
Approximate load	Full	1.2	Half
Quality of steam	98.7	99.2	99.2
Average steam pressure, pounds	93	96	90
Average revolutions per minute	430.5	432	435
Indicator springs	80	80	80
Indicated horse-power	30.3	36.6	17.4
Indicated friction horse-power	1.18		
Indicated friction per cent.	4		
Water condensed per hour, pounds	1234	1535	808
Water per indicated horse-power per hour observed, pounds	41	42	46.3

A WELL LIGHTED STORE

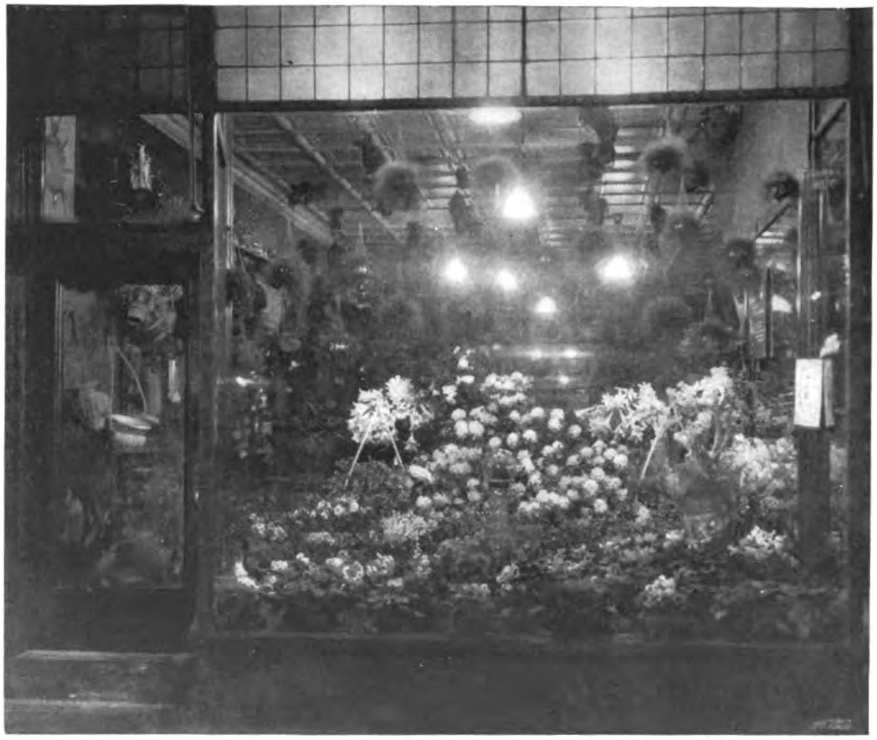
By R. B. Parrott

The progressive merchant fully realizes the advertising value of a well-lighted store and windows, and an actual installation which shows a decided improvement over methods hitherto considered satisfactory and which affords at the same time ample evidence of reduced operating expense, will always receive his careful consideration.

The store of S. A. Anderson, located at 440 Main St., Buffalo, N. Y., and illustrated herewith, is a good example of the economical and highly efficient lighting obtained by the use of General Electric tungsten lamps in combination wlth holophane reflectors.

Prior to the installation of these lamps, the store was lighted by three enclosed arc lamps and the windows by fifteen 16 c.p. carbon incandescent lamps mounted in a reflecting gutter. With this equipment the store was as well lighted as its neighbors, but since the installation of the tungsten lamps, it stands out conspicuously as an example of effective illumination.

As the very practical question of cost is of vital importance in store illumination, it will be well to compare the amount of current consumed under the old and the new arrangements, bearing in mind that with tungsten lamps the quality and distribution of light is far superior to that obtained from carbon filament lamps; the light is, in fact, the closest approximation to sunlight yet obtained artificially. The three arc lamps were 5 ampere, 110 volt direct current units, having a total power consumption of 1650 watts. The new equipment consists of four 250-watt tungsten lamps provided with satin finished holophane glass reflectors, the lower portion of the lamp bowls being frosted. The tungstens give twice the effective illumination obtained from the use of the arc lamps, with a power consumption of only 1000 watts as



Store of S. A. Anderson, Florist, 440 Main St., Buffalo, N. Y., Lighted by 250-Watt Tungsten Lamps fitted with Holophane Reflectors. From an untouched night photograph

against 1650 watts. This is a 40 per cent. saving, giving a reduction of 40 per cent. in the bill for the same length of service, or else 65 per cent. longer service for the same cost.

In the window the fifteen 16 c.p. 50-watt carbon incandescent lamps, with a current consumption of 750 watts, gave an effective illumination of 240 c.p. These were replaced by three 250-watt tungsten lamps similar to those in the store, and equipped with the same satin finished reflectors. The current consumption in this case was the same as with the carbon lamps; *i.e.*, 750 watts; but the effective illumination was more than three times as great, being 750c.p. as against 240 c.p.

In addition to this, it should be remembered that the periodical disturbance caused by trimming arc lamps is altogether avoided, as the tungsten lamp has an effective life of 800 hours, and unlike its predecessor, the carbon lamp, it will maintain its full lighting efficiency throughout its effective life. The light is not only evenly diffused, but the slight variations in voltage which occur in the average lighting circuit will not cause flickering in the tungsten lamp; its light remains steady.

The saving in bills for current consumption assured by the use of tungsten lamps is obvious, and it was Mr. Anderson's prompt appreciation of their many advantages that caused him to scrap the old lighting outfit in his Buffalo store and substitute G.E. tungsten lamps.

BUYING CARBON TOOL STEEL ON SPECIFICATION

By J. M. Darke

Three years ago the writer conceived the idea of buying carbon tool steel on a specification basis, in the same manner as many other materials used by large manufacturing concerns are purchased. When the subject was broached to those most interested, it was received with little enthusiasm. The manufacturers of carbon tool steel were not in favor of the idea, as it removed at once the value of their brand or trade names, upon which they had spent years of advertising, and which represented the real difference between their steel and the steel made by competitors. The master mechanics and shop foremen were somewhat doubtful as to its success, as the idea was so radically different from the system under which they had been working for years. Many of them were men of long experience, who had used certain brands of steel for years, and it seemed impossible to them that there were dozens of other brands equally good. It is also natural to feel that in adopting a scheme which removes the responsibility of making a choice in selecting steel, something quite personal has been lost.

Others objected to the idea on the ground that "chemical analysis was not the whole thing." This is true in a narrow sense. This same argument was advanced when the chemist was introduced into iron and steel foundries and various other industries. Through the lack of exercising ordinary common sense, the chemist came very near being an absolute failure in the iron foundry business. This would be the outcome if chemistry were applied in the same manner to a tool steel specification. Chemistry properly applied is a great aid in determining the quality of tool steel, but it will not tell whether the steel was made in an open hearth furnace or a crucible. The microscope will answer questions that chemistry cannot. The specification was therefore drafted to include both chemical and microscopical analysis.

A large number of American manufacturers of carbon tool steel were asked to submit samples representing their various brands. These samples were carefully analyzed, photomicrographs were made, and results compared. It was found that the steels grouped themselves into three grades, one about a 7 ct. base, the second about a 14 ct. base, and the third about a 22 ct. base; the latter usually being a "double special" steel, and generally containing some alloy.

The various tool-steel mills were visited by a committee, including the writer, and as representatives of a large consumer of tool steel, we were afforded exceptional facilities for investigating the plants. We found that all the mills visited were well equipped, both in men and apparatus, for making good tool steel, and that they were honestly trying to maintain a high standard. In short, there was no reason why any one of the mills visited could not produce as good steel as its neighbor.

With the above facts in mind, the following specification was drawn up and presented to the trade:

Specification for Carbon Tool Steel

(1) Tool steel to fill this specification will be required in five classes and three grades, as follows:

Class No. 1	0.75% to 0.85% carbon.
Class No. 2	0.85% to 0.95% carbon.
Class No. 3	0.95% to 1.10% carbon.
Class No. 4	1.10% to 1.25% carbon.
Class No. 5	1.25% to 1.40% carbon.

	Grade "A"	Grade "B"	Grade "C"
Manganese	0.25% to 0.45%	0.25% to 0.35%	0.25% to 0.35%
Silicon, not over	0.20%	0.15%	0.12%
Phosphorus, not over	0.03%	0.020%	0.010%
Sulphur, not over	0.04%	0.020%	0.010%

(2) The steel to be crucible steel properly melted in crucible, not so called "crucible analysis," with the exception of grade "A," which may be acid open hearth steel.

(3) The steel shall have been sufficiently forged to refine the grain, and forging stopped at such a temperature that the maximum refinement of grain will be obtained.

(4) Steel containing the exact minimum amount of carbon in any class will be considered as belonging to the class below.

(5) The steel shall be free from flaws and other imperfections.

The 22 ct. grade of steel was discarded; being an alloy steel, it could not be included in a carbon steel specification. A very low grade was added to cover such steel as would be suitable in open hearth.

TABLE GIVING CLASS AND GRADE OF TOOL STEEL FOR VARIOUS PURPOSES

	Grade "A"	Grade "B"	Grade "C"
Class 1 0.75 to 0.85 C.	Drop dies Dies for hammers in blacksmith shop	Hammers Drifts Punches Hot chisels	Cold chisels Cold sets
Class 2 0.85 to 0.95 C.	Cams		
Class 3 0.95 to 1.10 C	Sheet steel for springs	Lathe centres Jigs & templates	Misc. Steel for Blacksmith shop
Class 4 1.10 to 1.25 C	Spring (Coil)	Springs (Spec.)	Misc. steel for die room Large reamers Sheet steel for slotting saws Large dies Large taps Letters Figures Milling cutters (over 2" diam.) Drill rod
Class 5 1.25 to 1.40 C			Milling cutters 2" under Small dies Chasers Gravers Dies for heading machines

The various manufacturers were asked to quote prices on the different grades, which, with one or two exceptions, was done.

As an aid to the application of the specification, a table giving the class and grade of steel for various purposes was compiled, and is given herein with such parts omitted as are not of general interest.

This table was compiled by a tool-steel commitee composed of representative men from the departments using tool steel. Each article was fully and carefully considered and many of the selections (not appearing in table as printed) were the result of extended practical trials made in the shop under the supervision of a member of the committee. Valuable suggestions received from tool steel manufacturers were also incorporated. The table is subject to revision as experience renders necessary. New copies are issued to department heads and shop foremen whenever changes are made.

When tool steel is required by the various departments, requests for same are placed by the heads of departments with the Stock and Order Department. These requests, or orders, are then referred to the Laboratory Department to insure that the proper class and grade of steel is specified for the work in hand. The orders are entered in a record book, O. K.'d, and returned to the Stock and Order Department for placing with the steel manufacturer. A copy of the requisition as placed with the steel manufacturer is also kept on file in the Laboratory.

The tool steel is received by the Receiving Department, who notify the Chemical Laboratory and the shop foreman for whom the steel is ordered. The date of receipt is entered in the record book in the Laboratory.

The shop foreman upon receiving the steel, cuts off small samples, or, in case of large bars, takes drillings and sends them to Laboratory properly marked. Analysis for carbon, phosphorus and sulphur is then made, and if according to specifications, the shop foreman receives a copy of the analysis, which constitutes a release and the steel may be used. If not in accordance with specification, the Inspection Department is notified and the steel is rejected. Making the necessary records and analyses occupies very little time, and costs on an average fifty cents per sample.

A brief statement of methods employed in the chemical analyses may be of interest.

The carbon is determined by direct combustion of the drillings in a platinum tube, and requires 15 minutes time.

The phosphorus is determined by the Jones reductor method, and requires about 30 minutes.

The sulphur is determined by the iodine titration method, and requires about 30 minutes.

One operator can make several phosphorus or sulphur determinations in very little more time than is required for one determination.

Silicon tests are made occasionally and require 3 hours time, only a small portion of the work demanding the chemist's attention.

Microscopical examinations were made frequently when the specifications were first adopted, but it was found that the steel ran so uniformly good in this respect that now the examinations are made only occasionally. This would be the first test made, however, in case of trouble.

The steel is received without labels, but each bar is stamped with its class and grade, and the symbol designating the maker. For instance, steel of Class 5, Grade C, ordered from the Crucible Steel Co. of America would bear the stamp when received, 5-C-A; of Grade B, 5-B-A, etc.

Before adopting this specification we had 109 brands of steel listed, ranging in price from 7 cts. to 35 cts. per lb., any one or all of which might be in the factories at any time. The individual shop foreman decided whether he would use one or the other. It was impossible to keep all these brands separate, and the brand was no guarantee that the carbon content would be right for a given purpose. We were apt to get a high carbon steel for a hammer and a low carbon steel for a milling cutter, as all tempers were carried in the same brand.

The specification has greatly simplified stock keeping, as now five classes and two grades cover 98 per cent. of our requirements. We have uniformity of product and a considerable assurance that the steel contains the right amount of carbon to render maximum service when used for the purpose for which it is intended. This is due to the fact that the selection of steel is governed by the table before referred to, entitled "Table Giving Class and Grade of Tool Steel for Various Purposes."

As there are only three grades of steel called for in the specification, we have only three base prices. This gives a uniformity of prices and a definite basis for figuring costs.

The failures in hardening have been reduced to a minimum, because the hardeners know from the class of the steel the amount of carbon contained, and therefore the proper annealing and hardening heats. With furnaces properly equipped with pyrometers, and the carbon content of the steel known, most of the elements of failure in hardening have been removed.

While the primary object of the specification was to secure uniformity, it has considerably reduced the total cost of tool steel. This reduction of cost has been obtained, not only by competitive bidding on the specification, but by selecting high priced steel only where it was needed. The total saving cannot be readily determined, since so many factors enter into the calculation, such as increased life of tools and less breakage in hardening of parts involving large amounts of labor.

Specifications in general do not afford absolute protection against fraud, and are not so intended. They serve to standardize the article and describe to sellers just what the purchaser wants. If the material received is tested and does not measure up to the specification, it can be rejected without undue controversy. A tool steel specification does not differ in this respect from other specifications. During an actual trial of this specification for one year and three months we have found no disposition on the part of tool steel manufacturers to ship inferior steel. They are just as anxious as we are to have their steel a success, and work to the spirit of the specification as well as to the letter.

The success of a specification of this kind depends more on the make-up of the organization using it than on the seller. The organization must be in thorough sympathy with the ideals sought, or the plan will be a dismal failure. Prejudice in favor of certain brands and all petty personal jealousies must be laid aside, or it cannot succeed. Fortunate, indeed, is the organization that encounters none of these. There are usually some old employees who resent an innovation and who prefer to follow in the footsteps of their fathers. If, however, the plan is accepted and used in the proper spirit and with judgment, it will be found to work to the mutual advantage of seller and buyer alike.

SOME NOTES ON THE LOW PRESSURE TURBINE

By Morris B. Carroll

There are cases where the savings which a low pressure Curtis turbine will effect are so large that it is difficult to convince some persons that the claims made for these machines are not extravagant. In this connection, the following points may be of interest:

The standard four-stage high pressure Curtis turbines are so designed that the admission pressure to the last two stages is approximately atmosphere. In other words, the last stages of the machine constitute a low pressure turbine and furnish, in the case of a machine designed for equal work per stage, half the energy supplied to the shaft. If the steam consumption of the entire unit is 18 lb. per kw. hr., that of the last two stages considered alone would be 2x18 = 36 lb. per kw. hr. Of course, as these wheels work in vacuum, the loss due to friction and windage is very small as compared with the first stages of a high pressure machine, and consequently the efficiency is higher and the steam consumption less with a low pressure turbine than is indicated by the above rough approximation.

As the low pressure turbines are especially designed for the work required of them, it will be seen that the guarantees are conservative and entirely consistent when compared with the performance of the high pressure units. Practically all of the experimental work on Curtis turbines was done on machines operating with 1 lb. gage throttle pressure, and hundreds of tests have been run under conditions similar to those met with in low pressure turbine work.

One case of the combination of an engine and a low pressure turbine figures out as follows: When running non-condensing at 1000 kw., the engine has a steam consumption of 32 lb. per kw., or 32,000 lb. of steam per hour. The exhaust from the engine generally contains not in excess of 6 or 7 per cent. moisture. Allowing 8 per cent. there will be available 32,000 x .92 = 29,440 lb. of dry steam for a low pressure turbine. With this steam, a turbine having a steam consumption of 33 lb. per kw., would develop $\frac{29440}{33} = 893$ kw., making a total output of 1000 + 893 = 1893 kw. at $\frac{32000}{1993} = 16.9$ lb. of steam per kw. hr. That is, the low pressure turbine would add 90 per cent. to the output of the plant using the same steam.

With the same steam, the engine running condensing at 28 in. vacuum develops 1320 kw. at $\frac{32000}{1320} = 24.2$ lb.; that is, 320 kw. more than when running non-condensing. The combination of the engine and low pressure turbine gives 893 kw. more than the engine running non-condensing, or 573 kw. more than the engine running condensing. With a total of 32000 lb. of steam per hour, the relative performances are as follows:

Engine non-condensing	1000 kw. at 32 lb. per kw.
" condensing	1320 kw. at 24.2 lb. per kw.
" and turbine condensing	1893 kw. at 16.9 lb. per kw.

Another point of interest is that the maximum load which the engine will carry is 1265 kw. non-condensing and 1470 kw. condensing. With a low pressure turbine, the maximum load that could be carried with the same steam, would be 2500 kw.

While it is evident from the figures given that the turbine will utilize the benefits afforded by vacuum more efficiently than an engine, the reason for this may not be clear. In an interesting paper on "Steam Engine Economy" by Prof. J. E. Denton, read before the Mechanical Section of the International Congress of Arts and Sciences at St. Louis, Sept. 23rd, 1904, we find the following:

"The most economical piston engines, which, as we have seen, expand steam about thirty times, release their steam at the end of the stroke at 6 pounds absolute pressure; but they exhaust into a condenser, which, with a vacuum of 28 in., contains a pressure of about 1 pound absolute per square inch. If the expansion could continue until the pressure of 1 pound was attained before exhaust occurred, considerably more work could be obtained from the steam. This, however, *cannot be done in piston engines, for two reasons:* first, because the low cylinder would have to be about five times greater in volume, which is commercially impracticable; and second, because the velocity of exit through the largest exhaust ports possible, is so great that the frictional resistance of the steam makes the back pressure from 1 to

3 pounds higher than the condenser pressure in the best engines of ordinary piston speed."

The energy available in expanding the exhaust steam of an engine from 6 lb. abs. to 1 lb. abs. (28 in. vacuum) is 72400 ft. lbs., and from dry steam at 165 lb. abs. to 1 lb. is 250095 ft. lbs. That is, the most economical condensing engines reject $\frac{72400}{250095}=29$ per cent. of the energy available in the steam.

This figure is for the most efficient triple expansion engines, and of course the ordinary engines, which are less efficient, will reject more energy in their exhausts that would be available for use in a low pressure turbine.

"The steam turbine expands its steam to the pressure of the exhaust chamber, and as unlimited escape ports can be provided from this chamber to a condenser, it follows that the turbine can practically expand its steam to the pressure of the condenser."

Or in other words, the design of the turbine is such that it can utilize the energy which an engine must of necessity reject.

The foregoing should make it clear that the low pressure turbine proposition is entirely reasonable and is based on easily verified facts.

THE EXTENSION OF ELECTRIC SERVICE TO OUTLYING COMMUNITIES*

By J. S. Knowlson

Methods by which central station business may be profitably increased are always of paramount interest to the central station manager, and it is to one of these methods that I wish to invite your attention.

The progress of the electrical art and the education of the general public has made it possible today to profitably supply electric service to communities whose sizes would have rendered such service out of the question only a few years ago. Mr. Irving P. Lord pointed out these facts and described these conditions in a paper on "Electric Lighting in Small Cities and Villages," read before your Association not more than a year ago.

Within the states of Iowa, Minnesota, Wisconsin and the Dakotas, there are to-day 670 central stations: thirty-nine per cent. of these are in towns of twelve hundred inhabitants or less. On the other hand, there are 188 towns of over 600 inhabitants that have no electric service. It is safe to predict that within the next five or ten years nearly all of these will be supplied with electricity. While it is said that electric power properties in such small communities are not good investments, this statement is not borne out by facts. Many of them are making excellent returns, and it is unquestionably a fact that they are as successful as any other industries located in the same communities.

The last central station guide adds 210 names to the list of operating central stations, four of these stations being in the states above referred to. Eighty per cent. of these new plants were started in the smaller towns and villages, and every plant so started begets inquiries and discussion as to the advisability of establishing service in other communities of like size. The interest is widespread and vital, for each year people demand more conveniences: those which were regarded as luxuries ten or even five years ago are to-day necessities, even in the smallest communities. Besides this, the factor of local pride is in itself so strong as to have great bearing upon the establishment of plants in these smaller towns, and should not be underestimated.

While there can be little or no doubt that these 188 communities will demand electric service in the near future, it rests entirely in the hands of the station manager of to-day as to whether this service shall be supplied from existing central stations, or new local stations installed. Some of these towns and villages are so isolated as to lie utterly beyond reach of existing central station lines; but at least sixty per cent. of them are so located as to merit careful consideration as substation possibilities.

The extension of electric service to outlying cities and villages has been taken up systematically by a number of central stations during the past few years. That business obtained in this way is profitable, is best shown by the fact that year after year these stations reach out to new and more distant communities, thereby increasing their distribution zone and bringing more people within reach of electric service. As yet, however, this method of increasing central station business has not received the consideration at the hands of a large number of central station managers that it merits.

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* Paper presented before meeting of Northwestern Electrical Association.

Up to the present time two general plans for supplying outlying communities have been used with success. The first and simplest method is the formation of a local company in the community to be served, and the supplying of power to this local company at wholesale rates from the transmission lines of the central station. This plan has much to commend itself. From the view point of the community served, it makes the local company a matter of local pride—built by local capital, managed by local men, with the bulk of the revenue being directly put back into local circulation.

From the view point of the central station, such an arrangement removes the burden of franchise-getting, maintenance, repairs and operation, and reduces the amount of capital that must be put into the enterprise to the bare cost of the transmission line. The material reduction in first cost makes the plan particularly attractive to the smaller central stations, and to those that for any reason do not feel inclined to materially increase either their invested capital or operating expenses. On the other hand, the local companies in the communities so served stand as individual customers buying current at a low or wholesale rate, with the result that the gross revenue to the central station is less than it would be were the same amount of current sold at retail rates. Whether or not the net revenue is also less, is a matter for debate and individual consideration.

At the expiration of its contract, the local company may elect to buy power from some other source, and for this reason it is often well to arrange for an option on a controlling interest in the stock, or if this is impossible, to at least secure a long term contract.

The second method of approaching this problem may be termed a straight sub-station proposition; the central station company owning the pole lines and distributing systems and operating them as a part of its own plant.

In estimating whether or not the returns from any particular community will justify the supplying of power to that community, detailed consideration should be given to the following factors:

1. Revenue
   a Street Lighting
   b Commercial Lighting
   c Power
2. First Cost
   a Franchise and right of way
   b Transmission line
   c Local distribution
3. Operating Expenses
   a Depreciation, taxes and insurance
   b Cost of power
   c Maintenance and repairs
   d Bookkeeping

A fairly close estimate of revenue may be made by comparing the possibilities of a given community with those of similar communities already served. In making this estimate, however, the rapid progress in the art must not be underestimated. For instance, with the advent of the tungsten lamp commercial lighting has increased and customers heretofore unapproachable have been added to central station lines. If a day service is maintained, farms along the transmission line should be equipped with motors.

It is difficult to make any general remarks upon the subject of franchise and right of way. In obtaining such a franchise, it has been pointed out by those who have had large experience in these matters that it is always well to specify that power may not only be carried to the community, but also through it, in order that there may be no question raised if in future it becomes expedient to serve other communities beyond this particular town. For obvious reasons it is also well to specify and speak of transmission lines as long distance rather than high tension distribution. Right of way privileges are, as a rule, obtained along highways, but when poles are placed on private property, written permission should always be obtained, or a nominal rental paid to avoid any possibilities of future friction.

In considering the transmission line, attention must first be directed to the determination of a suitable voltage. Copper is always a considerable item, and the generating voltage should be stepped up when the saving in copper thereby obtained will equal or exceed the cost of suitable transformers. Line costs vary with local conditions, but for construction of this sort the simplest form possible is the best. Thirty-foot and often twenty-five foot poles are used, each pole carrying a two-pin cross arm; the third wire, if a three-phase circuit is run, being carried by a pin insulator on the top of the pole.

If it has been necessary to use a higher pressure than 2300 volts on the transmission line, this voltage should be stepped down through a bank of transformers located on the outskirts of the town, the transformers, protective fuses, and lightning arresters being mounted on poles in the simplest manner. In the local distributing system, the street lighting demands primary consideration. This lighting will probably be done by incandescent lamps of either the street series or multiple type. The series system will undoubtedly give more satisfaction, but it necessitates a tub transformer and some place to keep it. Local conditions will also clearly determine this point.

While the first costs of construction are comparatively easy to estimate, it remains for the ingenuity of the central station man to devise methods by which the operating and maintenance items of this semi-isolated load may be cared for most economically. Arrangements are often made with some local store to keep in stock incandescent lamps and supplies, and in return for the current consumed, to take charge of routine attendance, such as switching the street circuits on and off and the care of such slight troubles as replacing fuses, street lamps, etc. Further arrangement is often made in the same way for the reading of meters and the collection of bills on a commission basis. In other localities, the control of the street lighting circuit is automatically taken care of by a time clock switch which only needs to be wound up once a week.

Bookkeeping and office expense may be somewhat reduced by providing the meter reader with a manifolding bill book which has the meter reading recorded in duplicate and the reading multiplied by the rate; the original being left with the customer as his bill and the copy brought back to the office for file. The methods are legion, for wherever we find Yankee business men, we will find new and improved schemes for decreasing cost and increasing efficiency.

Although general figures are often misleading and as a rule are to be avoided in discussions of this sort, I present for your consideration the following table of data on transmission voltage, capacity, necessary outlay, and margin of safety and profit which may be expected from sub-stations in towns of various sizes at various distances from the central station.

Total investment includes transmission, transformers, meters, street lights and distributing system completely installed.

Population Served	Capacity of Sub-station		DISTANCE SUB-STATION FROM CITY LIMITS			
			3 Miles	6 Miles	9 Miles	12 Miles
500	25 kw.	Total Investment	4800	7500		
		Margin of Safety and Profit	11.5 %	3.7 %		
		Transmission	2300 Volts 3-phase	2300 Volts 3-phase		
1000	60 kw.	Total Investment	7600	10000	12000	14200
		Margin of Safety and Profit	21%	13.5%	10%	5.5%
		Transmission	2300 Volts 3-phase	11000 Volts 3-phase	11000 Volts 3-phase	11000 Volts 3-phase
1500	100 kw.	Total Investment	10000	12200	14000	16300
		Margin of Safety and Profit	25%	18.7%	13.9%	10%
		Transmission	2300 Volts 3-phase	11000 Volts 3-phase	11000 Volts 3-phase	11000 Volts 3-phase

Transmission

50 poles to mile. Cost of poles, cross arm pins, insulators, etc., set up ready to receive wire, $9.00 per pole. Energy lost in transmission, 5 to 10 per cent.

Gross income from all classes of service estimated at $4.50 per capita.

Operating Expense

Depreciation, insurance and taxes, 10 per cent. of total investment. Maintenance and labor, $ .50 to $1.00 per capita.

Cost of Power at Generating Station Bus Bars

1½ cents per kw-hr. (does not include depreciation, insurance, etc.).

Consumption of energy as recorded on station meters, 100 to 120 kw-hrs. per year.

Margin of safety and profit expressed in per cent. of total investment.

While these figures may serve as a guide to a very preliminary survey of the latent possibilities, the point which I desire to emphasize most strongly is that there are large opportunities for the profitable extension of electric service to outlying towns and villages; that these merit the consideration of the small central station as well as the large; and further, that the issue is one of to-day.

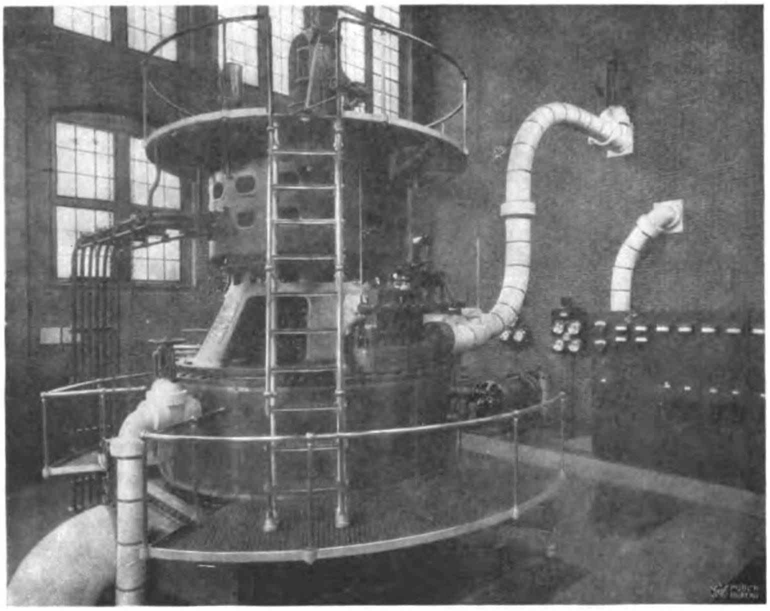
APPLICATION OF ALTERNATING CURRENT VARIABLE SPEED MOTORS TO PAPER CALENDERS

By J. M. Wade

Early in 1906 it was decided by Louis Dejonge Co., Fitchburg, Mass., Paper Coaters, to make an extensive addition to their plant. This extension called for much additional power, and a very much larger heating and drying system. It was finally decided to dispense entirely with the old power and drive, which consisted of reciprocating engines and belt transmission.

After carefully considering the electric drive for both the old mill and the new extension, the problem was brought to the attention of the General Electric Co., which concern, after having had most exact data and requirements given them for all purposes of power, drive, and heating and drying by exhaust steam, submitted a most satisfactory proposition, which was accepted and put into contract form.

An entirely new generator house was erected, in which was installed a 1500 kw. Curtis Steam Turbine with complete auxiliaries. The turbine is designed to operate noncondensing, the exhaust steam being used for heating and drying purposes. The steam leaves the turbine through a 22 inch exhaust pipe which, after passing through an underground tunnel, enters the mill and rises to the top floor. From this point the riser becomes a horizontal steam main, which gradually diminishes in size (to 10 inches diameter); this supplies all heating and drying coils as it passes through the upper story of the mill.



Power House, showing 1500 Kw. Turbine and Generator, 25 Kw. Turbine-Driven Exciter, and Switchboard. Louis Dejonge Company

The steam after leaving the coils passes into 6 inch returns, which lead to a receiving tank for the condensation water. As there is no oil required or used for lubricating the parts of the turbine with which the steam comes in contact, this water is entirely free from oil and is returned to the boilers. This is not the case with reciprocating engine exhaust, and in such cases oil separators have to be depended upon to keep the oil out of the boilers.

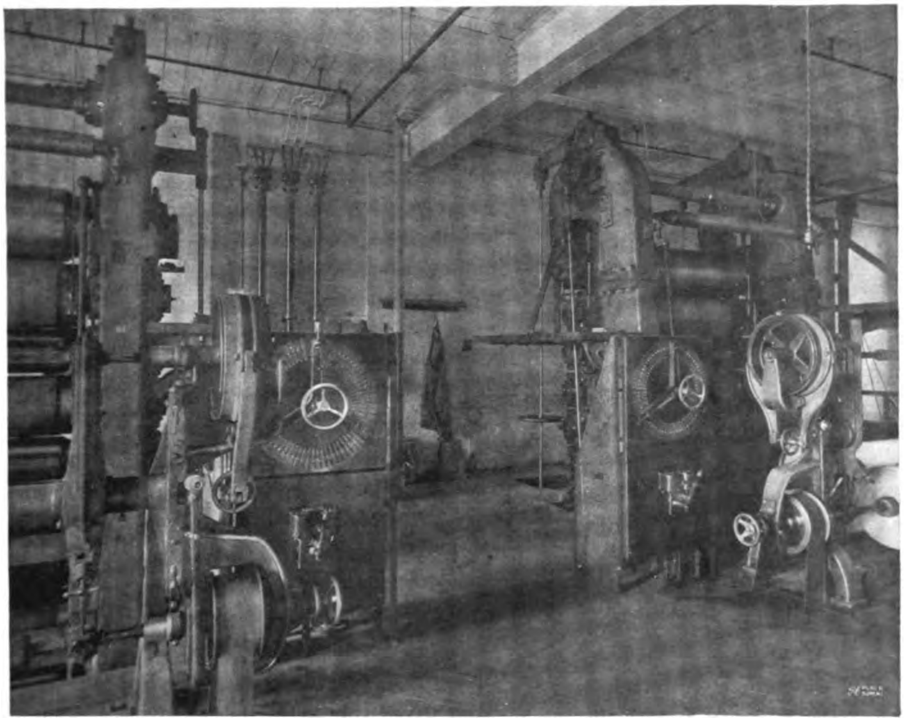


Fig. 2. Nine-roll 66 in. Calender and Controlling Panel. Driven by a 75 H.P. Motor Located in Basement and Geared to Lower Rolls. Louis Dejonge Company

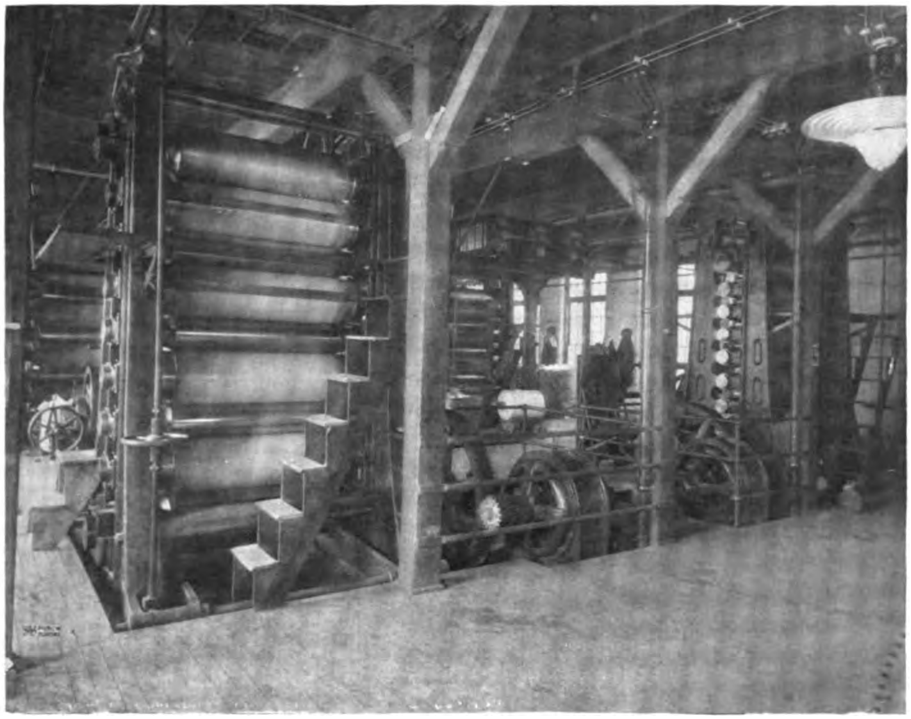


Fig. 3. Finishing Calenders Driven by 75 H.P. Form M Motors, showing Gearing. These Calenders were Formerly Driven by Friction Clutches, etc. Louis Dejonge Company

Direct connected to the turbine is a 1500 kw., three-phase, 60 cycle, 600 volt, alternating current generator, operating at 900 revolutions per minute. The generator receives its excitation from a 25 kw., 3600 revolution, 125 volt, Curtis turbine driven exciter of the horizontal type.

A six-panel switchboard is installed on the main station floor, for controlling the various power and lighting circuits. The panels, which are of natural slate finish, are supported on pipe framework and are located about five feet from the wall, with the oil switches, busbars and instrument transformers mounted in the rear.

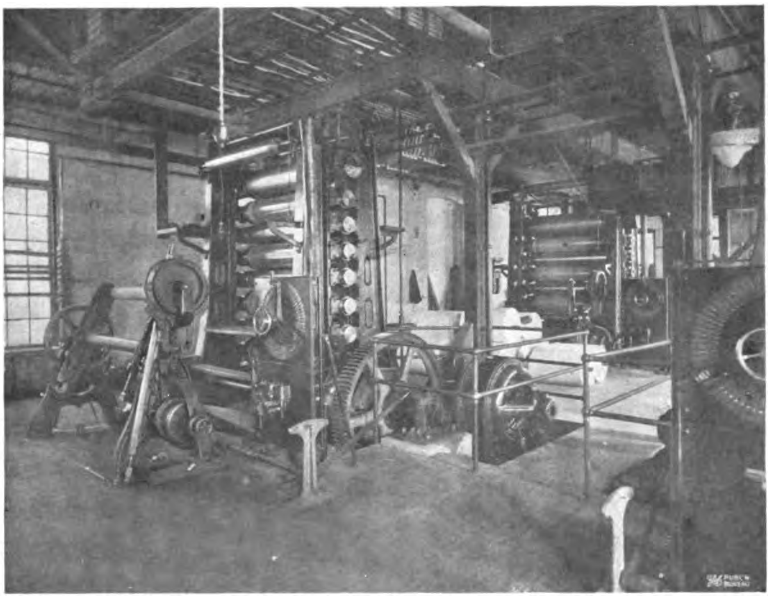


Fig. 4. Front View of Fig. 3

All oil switches are operated from the front of the switchboard by means of bell cranks and levers located underneath the main station floor. This arrangement provides a clear passageway between the panels and switches and makes all parts easily accessible for any attention that may be required.

An underground tunnel has been provided between the generator house and the mill for the passage of the turbine exhaust and the power and lighting wires, and at no place are they outside of the buildings or exposed.

The fourteen finishing calenders are driven by individual motors. These motors are of the General Electric variable speed type, and in each case drive through single reduction gearing, consisting of a raw-hide pinion on the motor, and a cast gear wheel with machine cut teeth on the lower roll of the calender; this arrangement entirely obviates the use of clutches. The motors are each furnished with a resistance in the secondary or rotor circuit. circuit, and an open face dial controller for starting and speed regulation, an interlocking device being provided between the oil switch and the dial controller to prevent the closing of the switch at any other than the off position which is connected to a dial type controller on the motor panel, and which allows the operator so to vary the speed of the motor that any intermediate paper speed from zero as minimum to 530 ft. per minute maximum may be obtained.

Twelve of the larger calenders are driven by 75 h.p., 550 volt, variable speed motors having a maximum no-load speed of 514 revolutions per minute; while the two smaller calenders are driven by 25 h.p. variable speed motors operating at a no-load speed of 600 revolutions per minute.

A slate panel is provided for the control of each motor, and is located at each side of the calendar. Each panel is equipped with an oil switch for the control of the primary of the dial. The oil switch is equipped with a series overload coil and a shunt trip coil. This shunt trip coil is used for stopping, and is connected with push-buttons located on each side of the calender reel, within easy reach of the calender tender.

A brake handle is also mounted on the face of the panel and is direct-connected to a mechanical brake, which is set by the push-buttons at the same instant that the switch is opened, thus insuring a quick stop of the calender, and protection for the operator, machine, and stock.

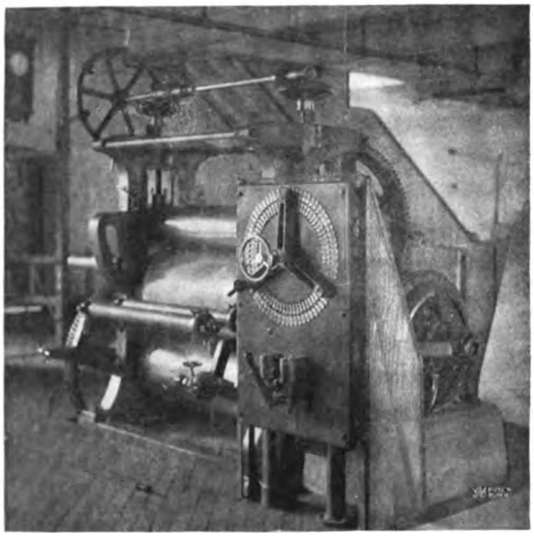


Fig. 5. 25 H.P. Form M Motor and Controlling Panel for Operating Calender; Motor Geared to Top Roll of Calender Louis Dejonge Company

A three-phase, 550 volt motor, of 1½ h.p. capacity, is installed with each of the larger calenders, for the purpose of lifting the rolls apart and handling the weight levers and reversing the reels. This motor is controlled by a switch mounted on the calender controlling panel.

The old calender drive consisted of a belt transmission to a 48 inch driving pulley, which was provided with friction clutches for throwing the high speed in and out, and a spur and pinion gear driven from an independent countershaft for the slow speed. Both speeds were operated by levers as well as the stop. A change from high to slow speed (or vice versa), or a sudden stop from high speed, jarred the gearing and calender badly, often breaking the paper in the machine, and defacing the calender and equipment. By the adoption of electric drive, all belts, counters and clutches have been eliminated, as well as the objectionable features mentioned above.

HIGH POTENTIAL PORCELAIN STRAIN INSULATOR FOR ARC LAMP HANGERS AND CUT-OUTS

By P. S. Bailey

Past experience has demonstrated the advisability of adopting a high potential insulator for the suspension of series arc lamps, both to prevent the grounding of the lamp or line and to protect the trimmer and other persons when coming in contact with the suspension rope or cable. With this object in view the General Electric Company has used successively insulators of glass (the triple petticoat), Hemingrey, and special compound, with particularly satisfactory results.

A new high potential porcelain strain insulator has lately been standardized for use with arc lamps, which is similar to that developed for high tension service and described in the November, 1908, issue of the Review. This device embodies all of the important features possessed by insulators heretofore used; this result having never before been obtained in any one type of insulator.

The salient features of this insulator are as follows: mechanical strength; high insulating qualities; excellent vitrification characteristics, resisting the entrance of moisture and the introduction of oils or vapors; elimination of tendencies to crack, warp, weaken, or deteriorate due to aging, atmospheric action, or severe conditions of service; and method of construction, preventing possibility of lamp falling to street should insulator be maliciously broken.

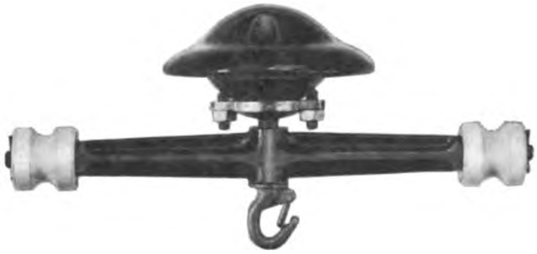


Fig. 1. Arc Lamp Hanger, fitted with Cross Arm and Strain Insulator

Fig. 1 shows the type of insulator which may be used for suspending lamp when no cross-arm or absolute cut-out is desired. The insulator is chocolate-brown in color and is constructed with two circular holes for purposes of suspension. These holes extend through the insulator at right angles, the one intended for the lamp-supporting cable (which is attached to the suspension hook and plate) surmounting the hole through which the line suspension cable passes. Thus it will be seen that the two supporting cables form loops which must engage each other in the event of the insulator becoming destroyed.

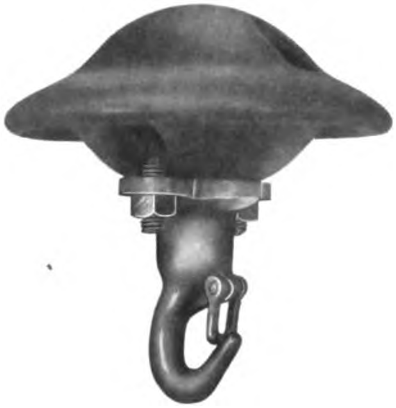


Fig. 2. Porcelain Strain Insulator for Suspending Arc Lamp

In Fig. 2 is shown the General Electric standard hanger for arc lamps equipped with strain insulator. This device is intended for all cases where no absolute cut-out is required, but where cross-arms for supporting the wires attached to the leading-in cables or terminals of the lamp are necessary.

That the strain insulator has been easily adapted to the General Electric Form 4 series cut-out is apparent from Fig. 3, which shows a standard Form 3 D.C. series luminous arc lamp suspended therefrom. This cut-out, so equipped, has been furnished in many instances where very severe conditions have existed, and it has proven most satisfactory. Naturally, the cut-out can be used to equal advantage with either the D.C. series or A.C. series carbon arc lamps.

All insulators are provided with holes sufficiently large to accommodate the steel cables, galvanized chain, or hempen rope ordinarily used for this class of work. There are different views as to the superiority of the various methods of suspension and the insulator has therefore been made adaptable to them all.

The device withstands a potential of between 40,000 and 50,000 volts under the most severe weather conditions, thus showing a disruptive strength much in excess of any conditions which will be met in lighting service. It has been subjected to a mechanical breaking load test of 8000 pounds, under which strain the suspending cables and fittings gave way. As the size of the cables could not be increased, the actual breaking point has not been ascertained, but the tests prove conslusively that the strains imposed by actual service conditions are amply provided for.

In order to prevent rocking, the insulator is fitted with a clamping-plate and a stud or hook on the under side which is affixed to the lamp supporting cable, thus effectually preventing motion and subsequent disalignment. It is considered good practice to use a filler of pitch in the orifice containing the line suspension cable. This can be melted and poured in around the cable, thus avoiding the accumulation of water and accompanying deterioration of the cable.

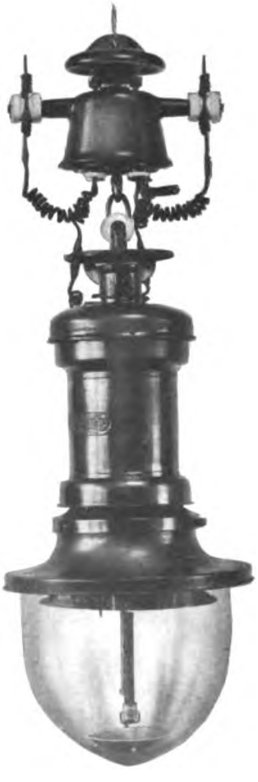


Fig. 3. Luminous Arc Lamp Suspended from Cut-out fitted with Strain Insulator

It is evident from the foregoing that the latest developments in the art have been taken advantage of to produce a satisfactory high potential insulator for supporting high tension lighting units.

EQUIPPING A LARGE RETAIL GROCERY STORE WITH TUNGSTEN LAMPS

By S. H. Conkey
Minneapolis Office, General Electric Co.

Yerxa Bros.' grocery store, No. 621-7 Hennepin Ave., Minneapolis, Minn., has the distinction of being the first store in Minneapolis that was completely equipped with the General Electric Diffuser.

The main store occupies a ground floor space of 8700 square feet. In the rear of the store proper a balcony of 2500 square feet is used for tea rooms and the offices of the company, the space under this balcony being devoted to the shipping and receiving departments. The main floor plan is shown in Fig. 1. The building is of brick and concrete construction, and the store is wired with iron conduit throughout. At the time of occupancy by Yerxa Bros. about two years ago, and up to the present time, the store was lighted by a mixture of direct current 5 ampere enclosed multiple arcs equipped with porcelain shades, and ordinary 16 candle-power carbon filament lamps; this arrangement producing very unsatisfactory results as to uniform and pleasing illumination.

The situation made itself more apparent when Bertrand and Chamberlain, leading Minneapolis architects, began plans for a general overhauling and refitting of the fixtures and interior of the store.

At this time, Mr. W. D'A. Ryan, Illuminating Engineer of the General Electric Co., Schenectady, New York, was called in to suggest a system of lighting that would raise the general standard of illumination throughout the store, and at the same time eliminate the objectionable features of artificial lighting as much as possible.

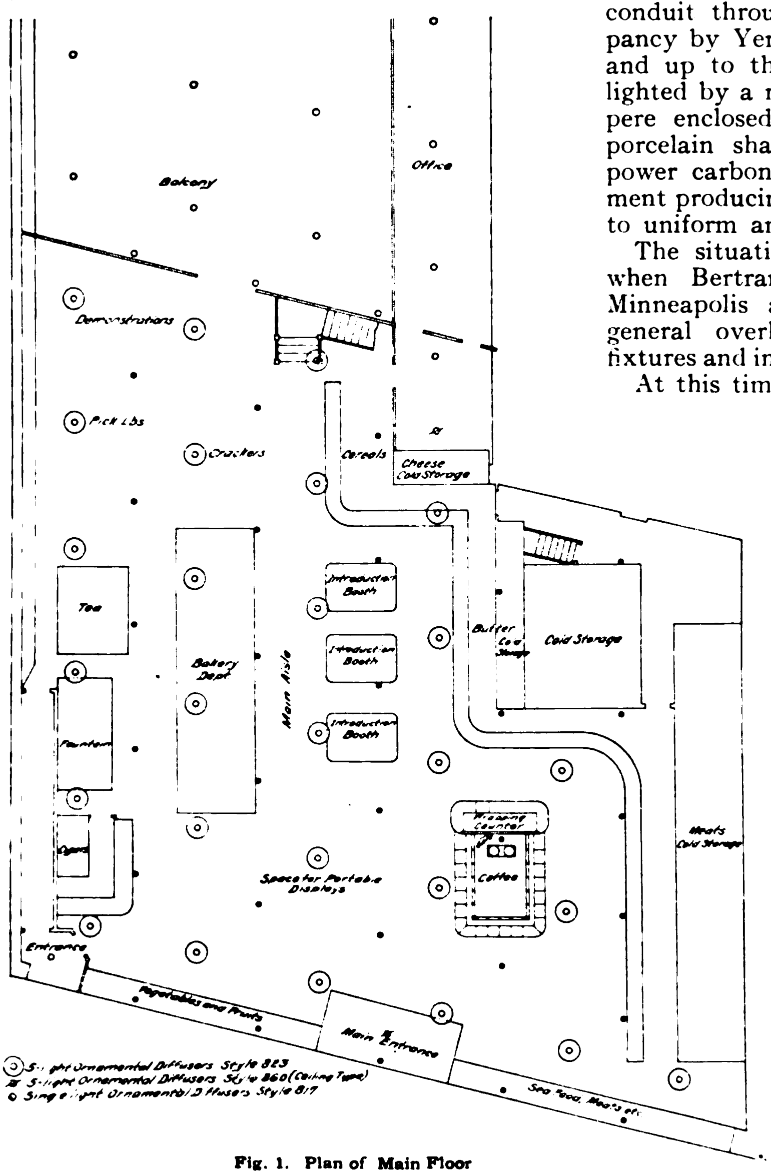

Balcony
Office
Demonstrations
Pickles
Crackers
Cereals
Cheese Cold Storage
Tea
Bakery Dept.
Main Aisle
Introduction Booth
Introduction Booth
Introduction Booth
Butter Cold Storage
Cold Storage
Fountain
Meats Cold Storage
Weighing Counter
Coffee
Space for Portable Displays
Entrance
Vegetables and Fruits
Main Entrance
Sea Food, Meats etc.
5-light Ornamental Diffusers Style 823
5-light Ornamental Diffusers Style 860 (Ceiling Type)
Single-light Ornamental Diffusers Style 817

Fig. 1. Plan of Main Floor

Two possible systems of lighting were considered: arc lamps with light balancing selective diffusers, and tungsten lamps. On account of the architectural features and the fact that considerable steel ceiling would have to be removed in order to properly install the ceiling diffuser system, thus entailing considerable expense, it was considered out of the question. The outlets for the arcs had originally been placed in the center of the panels, with 16 ft. centers, and in order to minimize the expense, it was decided that these outlets should be used so that no changes in

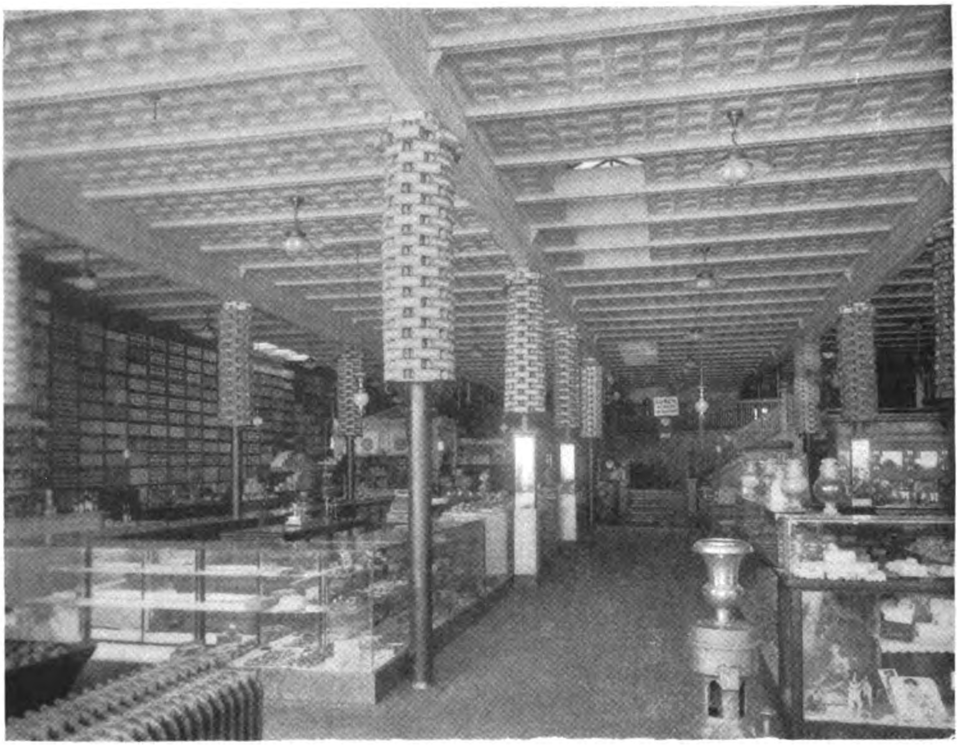


Fig. 2. Yerxa Bros.' Grocery Store, Minneapolis, by Daylight

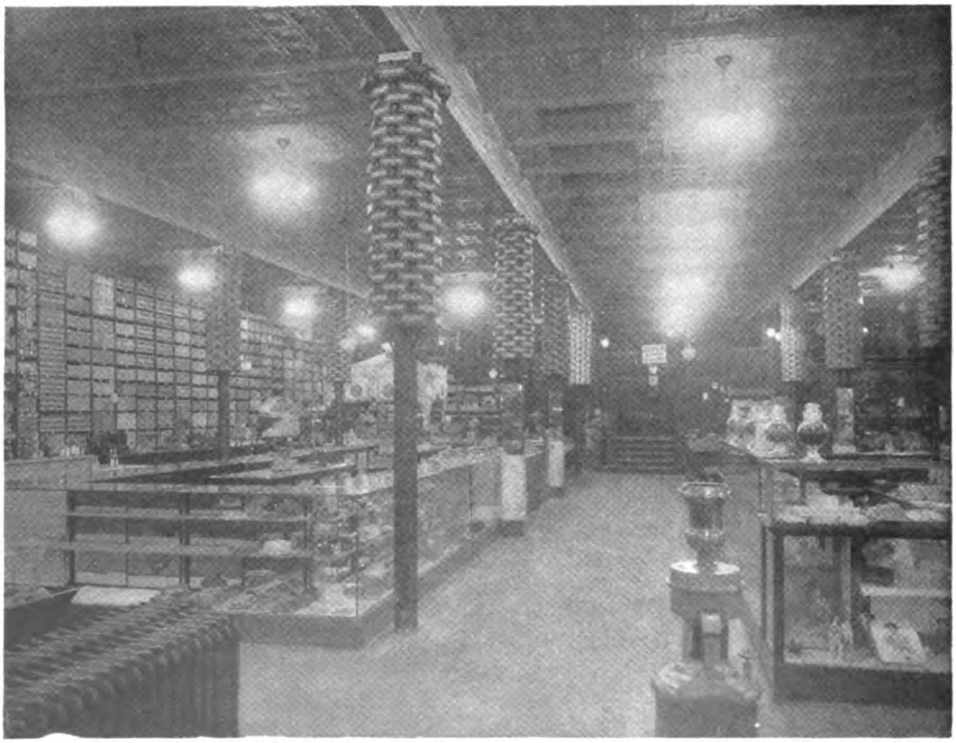


Fig. 3. Yerxa Bros.' Store at Night, Illuminated by G.E. Tungsten Economy Diffusers

the wiring would be necessary; the initial cost and maintenance being carefully considered in all cases. The scheme finally adopted for the general lighting of the store, was to place General Electric tungsten economy diffusers, fitted with opal granite art glass shades and frosted glass bowls, on the outlets as originally located; each diffuser to carry a complement of five 100-watt clear tungsten lamps. These diffusers are hung on chains 1 ft. in length, bringing the bottom of the fixture 16 ft. from the floor.

Each of the 26 diffusers used is controlled separately, the switches being located in two banks, one bank on each side of the store; the balcony lights being controlled in four sections by switches located adjacent to them.

The ceiling of the balcony is 8 ft. high, and it was necessary to devise some scheme that would give proper diffusion and also permit of sufficient head room. This was accomplished by using the single light diffuser secured by a short canopy fixture and equipped with opal granite glass ware. Each unit carries one 100-watt tungsten and is spaced similarly to the economy diffusers in the general store.

The main entrance, which is of the vestibule style, is lighted by one ceiling type diffuser; and the side entrance, which is only about 8 ft. square, has double doors and is cared for by one 100-watt tungsten equipped with the same style glassware as that used on the balcony.

The general illumination of the entire place has been increased considerably, without producing the glare or harshness so apt to be found in highly illuminated places. At the same time the light source is not screened so much as to produce a flat effect, the faint shadows having a tendency to effectively bring out the objects displayed.

The total installation consists of 147 100-watt tungsten lamps, 130 of which are used on the main floor, the remainder being installed on the balcony and in the entrances. The lamps are so distributed over the entire area of 11200 square feet that an average of 1.3 watts per square foot of floor space is obtained. The light intensity varies somewhat as conditions demand, the main floor having the benefit of a stronger illumination than the balcony or entrances. The long angle at which the light strikes the walls and show cases eliminates the necessity of providing individual show case or local lighting. The cold storage cases in the meat department, which are about 8 ft. deep by 10 ft. high and run the entire length of one side of the store, are provided with large plate glass fronts. These boxes are surprisingly well lighted.

The opposite side of the store is used exclusively for canned goods. The shelves running to the ceiling are very evenly lighted, it being possible to distinguish the labels on the top tier of goods while standing a considerable distance away on the floor below.

The lighting of the balcony or tea room, while not of so great an intensity as the balance of the store, is very soft and pleasing, the diffusion being very marked on account of the quality of glassware used. This part of the store, being used exclusively as a cafe and rest room, does not require the amount of light per square foot that is necessary in the general store. The office lighting is carried out on the same plan and produces a soft working light which, with the absence of the bright spots, produces a minimum amount of eye strain. The use of individual desk lights is entirely done away with.

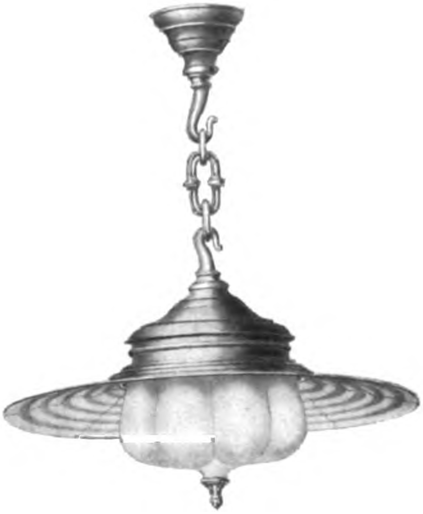


Fig. 4. Ornamental Tungsten Economy Diffuser with Plain Streaked Oxidized Copper Casing and 26 in. Art Glass Diffuers

The general impression on entering the store is one of comfort and hospitality, the light effect putting one at ease. To the passer-by, the store presents a very inviting appearance, and it is possible to clearly see objects in the rear of the store while standing on the walk outside—a result not often obtained by artificial lighting.

Fig. 4 illustrates the style of diffuser used.

OBITUARY

It is with profound regret that we record the death of Mr. Otto Holz, of the Standardizing Laboratory of the General Electric Company. Mr. Holz died on March 10th, after a few hours' illness.

He was born about 45 years ago in Koenigsberg, East Prussia, and was educated at the "*Graue Kloster*" High School in Berlin. He first became interested in scientific work through assisting his father, Dr. Alexander Holz, in some early experiments.

About 20 years ago Mr. Holz came to the United States and for a short time was engaged in working on arc lamps in New York City. He then went to Kansas City, where he became interested in laboratory and instrument work through his experience with Edison chemical meters, which were then in general use on the large supply systems.

From Kansas City he went to Lynn and engaged in general experimental work in the laboratory, giving special attention to the investigation of alternating current waves and magnetic phenomena. This class of work received a large share of his attention up to the time of his death.

In 1895 he was transferred to the Schenectady laboratory, where he continued his work along the special lines referred to, expanding this field to cover a variety of original work. Although actively engaged since his arrival in this country, he still found time to continue his studies, and became exceptionally well informed on mathematics, languages, and general physics; as well as on matters more specifically relating to electrical engineering.

He was extremely modest and retiring in manner, yet independent and original in thought.

Mr. Holz had few intimate friends, but was much liked by those who knew him well. He continually had in mind the welfare of others, and was always ready to assist anyone in obtaining a clearer understanding of those subjects with which he was so familiar.

Mr. Holz is survived by his wife, parents and sister.

PUBLICATIONS

The following publications have been issued by the Publication Bureau of the General Electric Company during the past few weeks.

4632 Annual Fan Motor Catalogue. Contains descriptions, prices and illustrations of all styles of fans for both alternating and direct current circuits, including desk, wall bracket, column and ceiling types In addition to these, a line of small alternating and direct current motors for sewing machines, buffers, drills, blowers, and other small power purposes are shown.

4637 Tungsten Lamps for Battery Service. Describes and illustrates complete line of tungsten lamps for all classes of service where battery power only is available, or where the ordinary lighting circuit is unsuitable. The lamps range in size and voltage from ½ to 30 c.p., 1½ to 20 volts; the smaller sizes being supplied in miniature and standard Edison bases, and the larger sizes in the standard Edison base only. The high efficiency of the tungsten filament renders it especially suitable for battery power, where high efficiency is of prime importance.

4638 Small Capacity Central Station Switchboard This publication contains information which is intended to be of assistance to engineers in designing switchboards for stations of moderate size. It includes outline drawings and wiring diagrams of switchboards for both alternating and direct current, and gives a list of the meters, switches, rheostats, etc. required.

4640 Large Shell Type Transformers. Sets forth the relative advantages of oil cooled, water cooled, and air blast types of transformers of various sizes. The publication describes the mechanical and electrical features of General Electric transformer construction; it is well illustrated, and contains a table of data to assist customers in determining whether air blast or water cooled transformers will be more suitable for a given installation.

4641 Electric Light and Power in the Lumber and Wood-working Industry. The advantages of electricity for the illumination and operation of wood-working mills, and the relative merits of alternating and direct current for this service, are clearly set forth. A description, with illustrations, of the electrical equipment of the Great Southern Lumber Company of Bogalusa, La., is also included.

4643 Direct Current Instruments. Describes the general electrical and mechanical features of types D-2 and D-3 voltmeters and ammeters. It is well illustrated and contains full size reproductions of meter scales for various capacities. Dimensions of the meters and shunts are also given.

GENERAL ELECTRIC REVIEW

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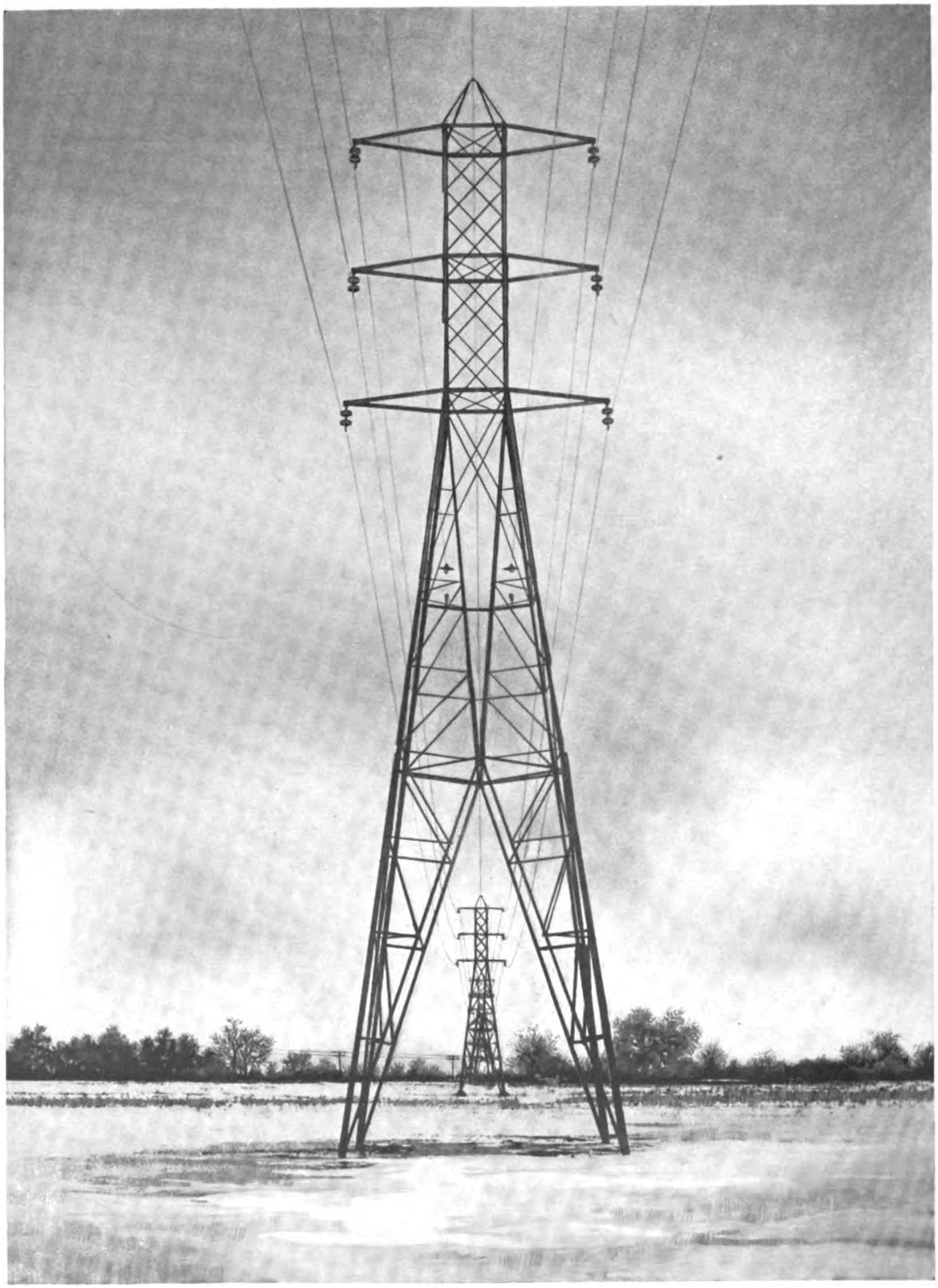

Schaghticoke-Schenectady Transmission Line, Schenectady Power Company
(See page 214)

GENERAL ELECTRIC
REVIEW

SYNCHRONOUS MOTORS

Synchronous motors have played an important part in power distribution since the use of polyphase currents began, and even before that a few single-phase motors of this type had been put into service. The fact that synchronous motors cannot start with a heavy load, as is pointed out by Prof. Crocker in his paper, has greatly limited their general application. Their limit in this direction is, however, not so great as is frequently supposed, and there are many applications where these motors can start without objectionable disturbance to the line. Such motors can easily be made to have a starting torque of about 25 per cent. of full load torque with full load current on the line.

Another handicap in the use of this type of motor is that the fields must be excited with direct current. This usually requires an exciter for each machine, since they are generally too far apart to use exciters in common. In case motors are grouped, as is often the case when they are used for driving d.c. generators or a.c. generators of a different frequency from the power line, the excitation may be supplied from exciter busses. If the driven generator is an alternator, the same source of excitation can be used for both motor and generator.

Synchronous motors can be built for high potential circuits much more readily than induction motors, and they usually have a higher efficiency. One of the greatest incidental advantages of synchronous motors is the power of controlling the power factor of a system by regulating the strength of the fields of the motor. This is so important that in many instances synchronous motors are driven from a system for this purpose alone, without doing any other work; these motors are called "rotary condensers." By the use of over-excited synchronous motors, or rotary condensers, the power factor of a line may be maintained approximately at unity. This greatly reduces the line and generator losses, where a mixed load is carried which would ordinarily produce a low power factor.

The paper by Prof. Crocker treats this subject in such a simple manner that its study will be of great value to engineers in obtaining a clear conception of what takes place in a synchronous motor under varying conditions of load and field excitation.

H. G. Reist

Iron and Steel

In this issue of the Review, we publish the second of Mr. Darke's articles upon iron and steel, the first, "Buying Carbon Tool Steel on Specification" having appeared in the April number.

Of the many and varied materials utilized by the engineering professions, the most important by far is iron and its derivatives; notwithstanding this fact, the manufacture, composition and treatment of iron and steel, and the influence that these factors have in rendering the resultant products adapted to the purposes for which they are employed, is, to many electrical engineers at least, a subject more or less hazy.

In the articles which Mr. Darke has consented to give us, the treatment of the topics will be simple, and in portions elementary, and for this reason some of the facts presented may already be familiar; but in view of the importance of the subject, a brief review of the fundamentals of iron and steel manufacture should not be amiss, while those who have been unable to devote the necessary time to keep thoroughly abreast of the recent developments in this line, will find in Mr. Darke's articles much that is new and interesting.

From the unearthing of various implements and utensils it seems probable that the smelting of iron was carried on by prehistoric man; and since the dawn of history the records show that iron and steel were worked at a very remote period, Homer referring to the forging of iron, and Pliny describing oil tempering. Despite this early beginning, little seems to have been known until very recent years regarding the composition of these products, development having progressed rather along the lines of methods of manufacture; though here too much survived that was both crude and inadequate. For example: the modern Catalan forge, except for its artificial air blast, and in respect to size, differs but little from those early appliances for the extraction of iron, accredited to Tubal Cain. The refined modern facilities for research which have become available within the past few years, have, however, revealed the nature and composition of these products; and this information has been instrumental to no small degree in introducing rational methods of thermal treatment, and has led to the discovery of the various alloy steels and their utilization for the purposes for which they are specially adapted.

The Schaghticoke Transmission Line

In the last issue of the Review, we published a description of the recently completed hydro-electric plant at Schaghticoke, the article dealing with the hydraulic development and the construction and equipment of the power house. The subject is continued this month in the article by Mr. Liston, describing the transmission line.

This line, while in no wise unique in construction, and while embodying no radical departures or experiments in engineering practice, is interesting as the first example of high potential transmission lines in the East to embrace several features that have been employed to advantage in southern and western systems. Among these may be mentioned the superposing of the phases, as in the Stanislaus, Cal. line; the use of disk type insulators, of the suspension and the strain varieties; and the employment of a lightning guard wire running the entire length of the line and grounded at each tower. The care which was taken in stringing the cables in order to equalize the stress at the insulators is also an interesting feature.

The determining consideration in the construction of this line was reliability of service, and to this end neither trouble nor expense was spared. The duplication of the power circuits for the purpose of insuring this continuity of operation is an example of this.

Developments in Transformer Apparatus

The history of transformer development is, fundamentally, the story of the solution of the problem of heat dissipation.

The iron and copper losses in a transformer, appear, of course, in the form of heat, and while in properly designed apparatus these losses are small as given in terms of percentage of total output, in the larger sizes now in use the actual number of heat units is enormous. It therefore follows that unless efficient means are provided for the dissipation of this heat and the maintenance of a reasonable temperature within the transformer, carbonization of the insulation, and mechanical displacement due to expansion and contraction will result.

With the first transformers, being of small capacity, the superficial area was sufficient to radiate the heat, but with the larger sizes simple radiation from the surface was found to be inadequate. This was due to the fact that the capacity increased practically in proportion to the weight; *i. e.*, to the cube of the linear dimensions, whereas the cooling surface only increased as their square.

It became imperative, therefore, that some means be devised to overcome the difficulty, and for this purpose air ducts were introduced into the coils to increase the available cooling area. As the size of transformers still increased, this was followed by the use of the air blast, oil cooling, etc. The successive improvements in this last method, and the reasons leading to their adoption, is the introductory subject in the article "Recent Developments in Transformer Apparatus" appearing in this issue of the REVIEW.

Other headings of Mr. Tobey's article are as follows: "Experience with oil-filled leads"; "The Development of the Series Transformer"; "Recent Designs of Lightning Transformers"; "The Tungsten Lamp Compensator"; "Hardening and Annealing Furnace"; "Transformer Testing Equipment." In this last, an interesting description is given of the elaborate testing facilities available at the Pittsfield works of the General Electric Company.

THE SYNCHRONOUS ALTERNATING CURRENT MOTOR*

By F. B. Crocker and M. Arendt

The synchronous alternating current motor is merely an *inverted alternator;* that is, the same machine may in general be used as a generator or motor. The simplest of this type is the *single-phase machine*, and a study of its characteristics will also be explanatory of the action of the corresponding polyphase motors. The single-phase synchronous motor is not at all self-starting (unless provided with special starting device), while the polyphase synchronous motor is self-starting without load, in which limitation both differ from the majority of other electric motors. It should also be noted that this type of motor requires a direct current supply for field excitation.

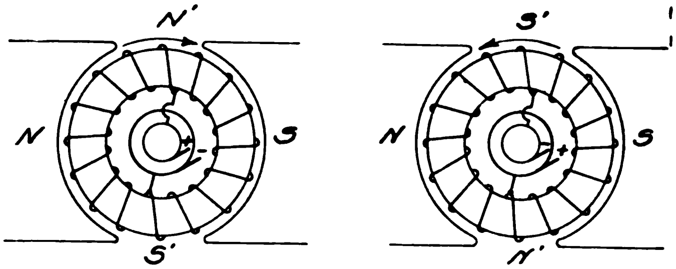

Fig. 1. Variation of Armature Polarity

Not self-starting for following reasons:

The rotation of the armature of a direct current motor is due to the fact that an unidirectional torque exists between the armature and the field. In case of increase in load, the torque is augmented due to a slight decrease in speed, which results in a reduction of the motor counter e.m.f. and thus allows a greater armature current to flow, producing a corresponding increment in the driving effort of the motor.

In the case of a synchronous motor we have the following conditions: A field excited by direct current and an armature supplied with alternating current. The first condition provides a field of fixed magnetic polarity, the second gives an armature, the current in which is alternating, therefore, the direction of rotation also tends to be variable. (Fig. 1.) If, however, the motor could be brought to such speed (by external means) that the half of the armature represented above in Fig. 1 would be below after the current reversed, a fixed polarity in space would result, because the top of the armature would always be of N polarity and the lower part of S polarity; producing a torque in one direction and therefore continuous rotation. To have this occur, the armature would, however, be obliged to revolve one-half a turn in the time occupied by one alternation of current, and a full turn in the duration of one cycle of current; in other words, the armature must generate a counter e.m.f. of the same frequency as the applied voltage. When this condition is fulfilled the motor is said to be operating in *synchronism*, hence the term *synchronous motor*. It is apparent that the speed of this motor must remain constant, since the torque must be unidirectional to maintain rotation, so that *the speed of any synchronous motor is fixed* by its number of poles and the frequency of the applied voltage; *i. e.*,

$$\text{speed in r.p.m.} = \frac{\textit{periods per sec.} \times 60}{\textit{pairs of poles}}$$

The polyphase synchronous motor is self-starting without load, because the polyphase currents set up a rotary magnetic field in the surface of the armature, which reacts upon the field magnet to produce mechanical rotation. The circuit of the field winding, however, must be open because the rotary field would not be sufficiently powerful in the presence of the field flux. After the rotary member is up to speed, the usual d.c. field excitation is established. To prevent excessive voltage being generated in the field coils, these are separated from each other and not connected together in series until synchronous speed is nearly obtained. It is also desirable when thus starting synchronous motors to use less than their normal operative voltage.

Action of Synchronous Motor under Varying Loads

As shown above, the motor must operate at a definite speed on a circuit of given frequency, or not at all. The field strength being also constant, the effective counter e.m.f. of the motor must be of constant value, therefore it would *seem* that with constant applied voltage, which is the practical condition, the armature current could not automatically increase to enable the motor to carry additional load. The peculiar action which occurs and allows of increased torque is explained as follows: Consider two ordinary single-phase alternators driven by independent prime movers, but with their armatures electrically connected in series and jointly furnishing power to an external load (see Fig. 2). The e.m.f. of the system (E_r) will under this condition be $E_m + E_g$ as shown by the wave and vector diagrams A and B, respectively (Fig. 3). Since there is inductance in the armatures and line, the current will lag behind the resultant e.m.f. or E_r by an angle θ. If the load should change or the steam pressure vary, the engine governors would tend to maintain constant speed; but one would naturally act before the other. This difference, however small, would cause one machine and its e.m.f. to fall behind so that its phase angle with respect to the current would be less, its load therefore greater, and the power required to drive it correspondingly increased. The converse is true of the other alternator, the consequence being that the former continues to drop back in phase until it is about 180° behind the other machine. Referring to Fig. 4, let us consider exactly what occurs. OE_g represents the e.m.f. of the lagging machine and OE_m that of the other, so that OE_r is the new resultant e.m.f. and OI the new current position, which maintains the same phase relation with E_r as before, because the constants R and L of the circuit have not changed. Let ϕ_m and ϕ_g represent the new phase displacement of E_m and E_g respectively with reference to the current. The load on each of the alternators is now $E_m I \cos \phi_m$ and $E_g I \cos \phi_g$ respectively; and since the angle ϕ_g is less than ϕ_m, the load $E_g I \cos \phi_g$ on engine G is greater than that on engine M, hence the latter tends to run faster while G will fall off in speed. The load on G increases more and more and the angle between E_m and I becomes greater until it passes through 90° after which $\cos \phi_m$ has a negative value so that the work done by alternator M is negative, *that is, it is operating as a motor*, the phase relations being represented in Fig. 5. Hence *the operation of two or more alternators in series is a condition of unstable equilibrium, unless they are positively connected together or to the same source of power* so that any speed change is common to both; otherwise, at the least variation in load or speed, they will instantly fall out of step and tend to pass into the condition of opposition or 180° phase relation.

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* This article will appear in a text book.

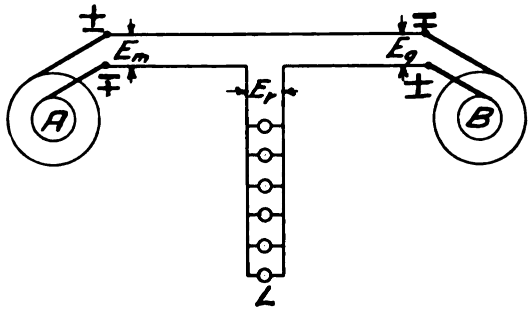

Fig. 2. Alternators Connected in Series

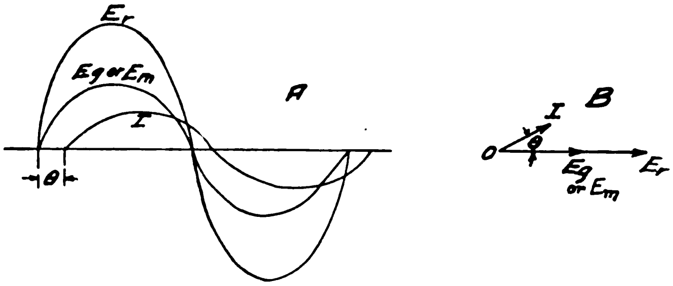

Fig. 3, A and B. Wave and Vector Diagrams, E.M.F.'s in Phase

The parallel operation of two or more alternators is a stable one, because if one machine tended to speed up, its voltage would increase and thus it would supply a larger current, carry a heavier load and be compelled by the action of the engine governor to slow down, while the under-loaded machine would tend to speed up, thus equalizing conditions. This statement is a general one corroborated by the fact that a.c. generators are successfully run in parallel in thousands of commercial plants. On the other hand, practical difficulties arise in some cases because a slight difference in angular velocity due to "hunting" of the governor, for example, may throw the machine out of synchronism. If, after the alternator M reaches the 180° position, we disconnect its mechanical driving power, it would continue to operate as a motor, provided the current fed to its armature be sufficient to supply copper losses and stray power torque. If this is not enough, armature M will tend to lag a trifle, causing the resultant e.m.f to increase so that more current flows. This increases its torque sufficiently to maintain rotation, unless the dropping back of M should be so great in duration or phase that the synchronous relation is broken.

The preceding facts may be summed up as follows: The ability of a synchronous motor to carry a variable load is due to the phase shifting of its e.m.f., which action taking the place of the speed changes of other types of motors alters the resultant e.m.f. so that the armature current automatically adjusts itself to the load.

Starting and Synchronizing of Synchronous Motors

The single-phase synchronous motor not being self-starting, as already explained, requires some auxiliary motor to bring it up to synchronous speed and into proper phase relation, before connecting it to the supply circuit. Such auxiliary starting device may be a series, repulsion or split-phase induction motor, or if the direct current field exciter is large enough, it may be used as the starting motor, being supplied with current from a storage battery, which at that time also furnishes the main-field exciting current. Small synchronous motors sometimes have the starting device made an integral part of them, as follows: The armature core is provided with an additional winding and commutator, which connected in series with an extra winding on the field cores, makes it possible to start the machine as a series motor. The commutated armature winding is connected across the main field after synchronous speed is attained and the main armature is connected to the supply lines, thus the machine becomes self-exciting

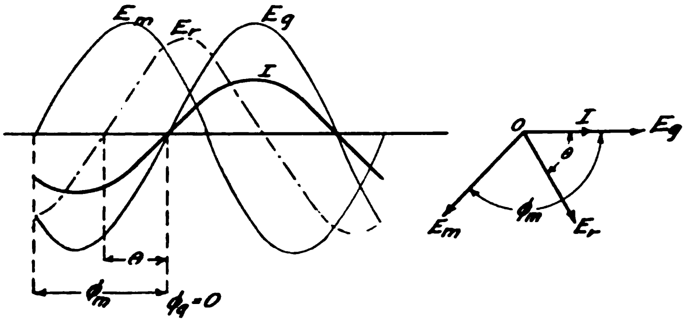

Fig. 5. Phase Relations Between Line Voltage, Current and Motor E. M. F.

Polyphase synchronous motors are self-starting, with about 10 to 15 per cent. rated load torque, through the development of a rotary field by the currents in the armature windings, which, acting upon the polar faces, drags the rotor around. The operation of thus starting up is as follows: The field circuit is opened, and the armature supplied with about rated load current at one-half rated voltage through a transformer or compensator. This causes the revolving member to rotate at a speed approximating that of synchronism, upon which the operator closes the field circuit, thus accelerating the rotor to synchronous speed, after which the armature is supplied with current at rated voltage and the machine is ready to carry its load. This method of starting may, however, especially if the motor be large with respect to the generators, cause serious voltage fluctuations, and it then becomes desirable to use some other starting devices, for example, an auxiliary machine as already described in the case of the single-phase synchronous motor.

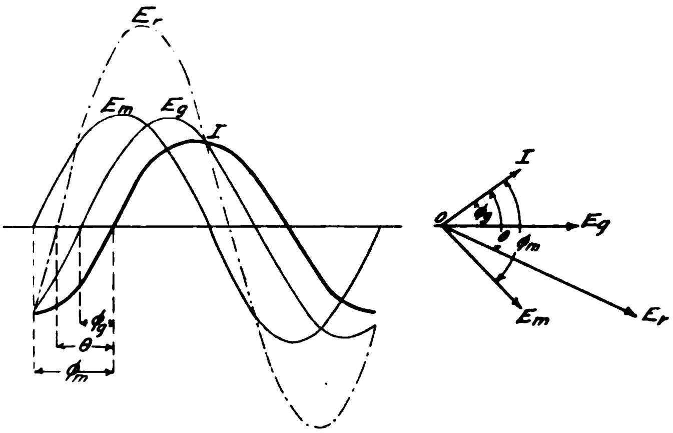

Fig. 4. Phase Relations Between Alternators in Series, Swinging Over to Parallel Conditions

It is impossible with ordinary mechanical speed-measuring instruments to determine the approach to synchronous speed as accurately as is necessary for the safe connecting of synchronous motors to the line; in addition the phase relations of the line and motor voltages must be correct. There are, however, simple electrical methods of determining when agreement in frequency and proper phase relations exist, the simplest of these being the lamp methods, one of which is as follows: In Fig. 6 L and M represent respectively single-phase line terminals and a single-phase synchronous motor, which can be connected by the double pole switch S. Two *synchronizing* lamps *l* and *l'* are connected respectively, as shown, across the two gaps in the circuit, controlled by the switch S. By means of the auxiliary starting motor, the synchronous machine M is brought to approximately the proper speed. If the rotor member of the motor is stationary, or if its frequency differs greatly from that of the circuit, the alternations of current and the corresponding flickering of the lamps *l*, *l'* are too rapid for the eye to detect, but when the motor frequency varies slightly from that of the line, whether higher or lower, the synchronizing lamps will glow for one moment and be black the next. The smaller the difference in frequency the less rapid the flickering. At the instant that the voltages are opposite in phase, and of equal value, there will be no current through the lamps, but when the voltages are in phase, their full sum is applied to the lamps which then glow at their maximum brilliancy. When the flashing becomes very slow the motor may be connected to the line by closing the switch S at the instant that the lamps cease to glow. If the motor continues to operate properly, its field strength may be adjusted so that the line current will be small after the auxiliary motor or starting up device is disconnected.

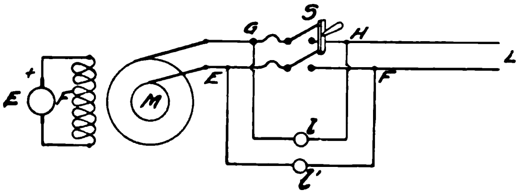

Fig. 6. Connections for Synchronizing Single-Phase Motor. (Lamps Black)

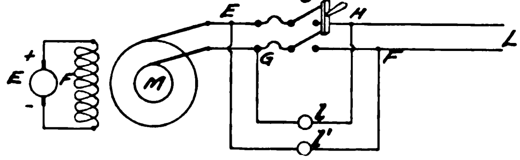

Fig. 7. Connections for Synchronizing Single-Phase Motor (for Maximum Light.)

It is better to connect the motor to the line as it approaches exact synchronism, rather than when it is departing from it; that is, the main switch S should be closed the instant the lamps cease to give light.

Owing to the fact that incandescent lamps do not glow with less than 30 or 40 per cent. of their rated voltage, it is impossible to determine exactly the minimum voltage difference which is the proper condition for connecting a synchronous machine, and thus the current passing between the machines and the line may be rather high upon closing of switch S. To avoid the danger of such rush of current, the lamps may be diagonally connected; that is, between G and F and between E and H (Fig. 7), in which case they glow at full brilliancy when the phase relation is correct. The lamps may also be replaced by voltmeters, which if connected as in the first instance would indicate zero voltage and in the latter case show full voltage.

The connections of the synchronizing lamps for a three-phase circuit are similar to the preceding, only three lamps are employed as shown in Fig. 8. If all three lamps simultaneously become bright or dark, the connections are correct, and the line switch may be closed at the instant of darkness. It may happen, however, that the lamps do not glow at the same instant, but successively. This indicates that the leads are not connected in their proper order. In this case, the motor lines should be transposed until the lamps brighten simultaneously. After the machines have been once properly connected their synchronizing can be accomplished with a single lamp. If the voltage of the circuit is too high for the direct use of lamps, transformers should be inserted as indicated in Fig. 9, their secondary coils being in series with each other and with the lamp 1. The latter will glow when the motor e.m.f. opposes that of the line, provided the connections of either the primary

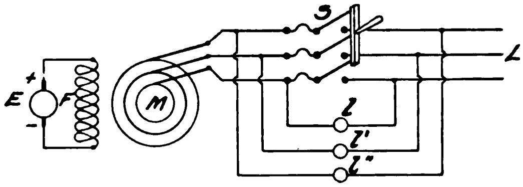

Fig. 8. Connections for Synchronizing Three-Phase Motor

or secondary coils are reversed, the former case being represented in Fig. 9.

It has become apparent with the continual increase in the size of units that means of synchronizing were desirable, even more perfect than those provided by the lamp methods just described, because serious trouble ensues if large machines with heavy revolving parts are connected together, when not in step. Such a device is secured in the synchronizer or "synchroscope."* This instrument consists essentially of a small induction motor, of which the fixed winding or stator is excited from the line, and the revolving member or rotor, supplied with current (through a phase splitting device) from the machine to be synchronized.

A rotating magnetic field is thus set up in the synchronizer, and the rotor thereof will revolve at a speed that is governed by the difference between the line and motor frequency. The shaft of the rotor is provided with a pointer, which, revolving with it, serves as an indicator. When the frequencies of the currents in the rotor and stator of the synchronizer are the same, the magnetic field due to both is no longer a rotary one, and the pointer remains stationary. This condition may, however, indicate only an equality of frequency, not necessarily one of correctness of phase. There is only one position of rest obtained by the rotor when frequency and phase agreement exist; and its pointer is so set that it points vertically upward when these conditions are secured. Accordingly, while agreement in frequency is indicated by the fact that the index of the synchroscope is stationary, the angular difference between such direction and the vertically upward one, shows the phase difference existing. Another feature of value in this instrument is that it also shows whether the motor (or incoming machine) is running too fast or too slow, because if running too fast, the pointer will move forward in a clockwise direction, while if it is revolving at too low a speed, the pointer will move in a counter-clockwise direction. Thus the synchroscope accurately indicates frequency and phase relations, and its use is to be recommended in connection with large synchronous motors.

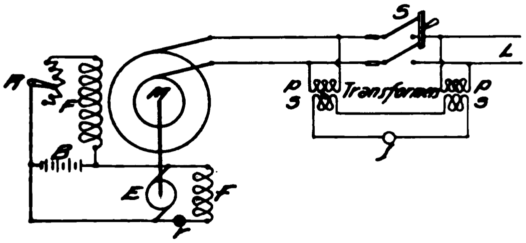

Fig. 9. Connections for Synchronizing on High Voltage Circuit. Exciter Used as Starting Motor

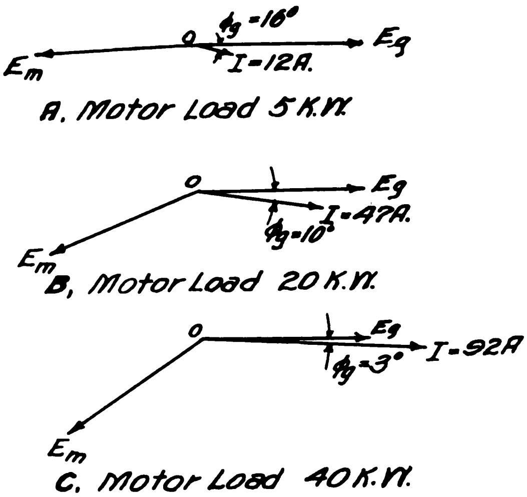

Fig. 10, A, B and C. Changes of Current Value and Position with Variation in Synchronous Motor Load

Phase relations between Constant-Line Voltage and Motor Current

The synchronous motor in practice is supplied with current from a constant potential circuit, and load changes cause the machine to draw currents varying not only in value, but also in phase relation with respect to the line voltage. Figs. 10, A, B and C illustrate the changes in current value and phase angle which occur in the case of a 30 kw. single-phase synchronous motor, when the load is 5, 20 and 40 kw. respectively, motor e.m.f. and line voltage being equal at 500 volts. These diagrams show that the angle ϕ_g between the current and line voltage becomes smaller and smaller as the load is increased, and would at about 45 kw. load reach a zero value, after which upon further addition in load it becomes greater again, in the opposite direction, but shifting from a leading to lagging angle.

Change of load is not the only method of producing variations in the angular relation between line current and voltage; it may be caused by adjusting the excitation of the motor, and this is frequently done in practice to secure a leading current.

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* *Electric Journal*, Vol. I, 1904, p. 692, Vol. IV, 1907, p. 497.

The actions occurring in a synchronous motor can most readily be studied by reference to vector or circle diagrams. Assume for example any condition of motor load and let the line e.m.f. be represented by E_g, the current by I, and the angle between them by ϕ_g. The angle θ, that exists between the resultant e.m.f. E_r and I (which depends upon the values of the frequency, the inductance L and the resistance R of the circuit) is theoretically a constant, but in practice it varies slightly since the permeability of the magnetic circuit is only approximately constant. Hence, knowing the line frequency and voltage E_g, the load amperes I, the watts input and the machine constants (L and R), we can readily draw vector diagrams representing the various phase relations of E_g, E_m, E_r, and I at any input, or any mechanical output, if we recollect that this latter is equal to the input less the $I^2_aR_a$ losses. Formulæ can be derived from these vector diagrams by which any one of their various components can be calculated if the others are known.

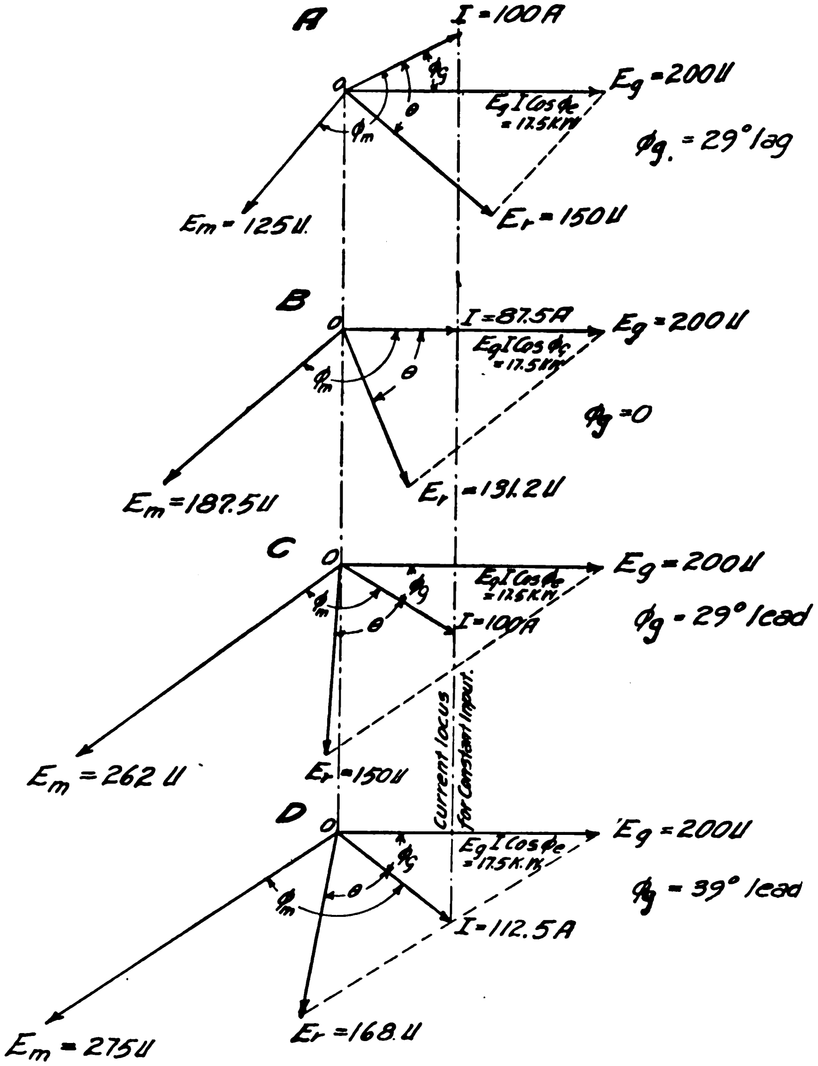
A
I=100A
Eg=200V
EgI Cos φg =17.5KW
φg = 29° lag
0
φg
θ
φm
Em=125V
Er=150V
B
0
I=87.5A
Eg=200V
EgI Cos φg =17.5KW
θ
φm
φg=0
Em=187.5V
Er=131.2V
C
0
Eg=200V
EgI Cos φg =17.5KW
φg
φm
θ
I=100A
φg = 29° lead
Current locus for Constant input
Em=262V
Er=150V
D
0
Eg=200V
EgI Cos φg =17.5K.W.
φg
θ
φm
I=112.5A
φg = 39° lead
Em=275V
Er=168V

Fig. 11, A, B, C and D. Variation of Power Factor (Cos ϕ_g) of Circuit, by Change of Motor E.M.F., Maintaining Constant Input

In Fig. 11A lay off OE_g as the impressed or line voltage, $O\,I$ as the current at angle ϕ_g from E_g; the value of E_r is proportional to the value of the current and is equal to $I\sqrt{R^2+2\pi fL^2}$, while the angle θ is $\cos^{-1}(R \div \sqrt{R^2+2\pi fL^2})$; hence lay off the value of E_r at angle θ ahead of I. The motor e.m.f. is then found by completing the parallelogram; that is, it is parallel and equal to E_gE_r, its true vector position and relative value being OE_m.

The power input of the motor is $E_gI \cos \phi_g$; the output including core and friction losses is $E_gI \cos \phi_g - I^2_aR_a$ or $E_m\ I \cos \phi_m = E_gI \cos \phi_g - I^2_aR_a$.

With E_g maintained constant, the current I may have any value for a given input depending upon the value of $\cos \phi_g$; for example, if $\phi_g = 0$ (or E_g and I are in phase) the power input is E_gI. Again ϕ_g may be a leading angle of same value as above, then the power is still $E_gI \cos \phi_g$.

The value of I and $\cos \phi_g$ for a given load depends upon the field excitation of the motor.

as follows: For instance, in Fig. 11B, let the motor input have the same value as above, but the current being in phase with the line e.m.f.; that is, $E_gI \cos \phi_g$ = const. and $\phi_g = 0$. The new position of E_r (the resultant e.m.f.) is substantially the same angle ahead of the current I since R and L have not changed materially, but E_r is smaller than before because I is less for the same load. The new value of E_m (the motor e.m.f.) is obtained by completing the parallelogram of which OE_g is one side and E_gE_r another. This new position and value of E_m is shown by the line OE_m which is longer than in the preceding case. This increase can only be brought about in one way; *i. e.*, by increasing the strength of the motor field, because the speed is synchronous and therefore constant.

In Fig. 11C, let us assume a motor load of the same amount as in the two preceding instances, but with the current leading the line e.m.f. by an angle ϕ_g equal to the lag in the first case (Fig. 11A). The angle θ between E_r and I remains practically constant because R has not changed and L only slightly. Lay off OE_r as resultant e.m.f. an angle θ ahead of OI. Completing the parallelogram we have OE_m representing the phase and value of the motor e.m.f. that corresponds to these new conditions. An inspection of this diagram shows that the motor e.m.f. (E_m) is now of still larger value. In fact the field strength of the synchronous motor can be increased so much that the motor e.m.f. is considerably greater than the line e.m.f., the result being that the angle ϕ_g becomes a large leading one; this condition being shown in Fig. 11D. Hence, if the motor field is gradually strengthened the line current can be made ultimately to lead the line e.m.f. This phenomenon of the synchronous motor is of value in the transmission of electric power since a *super-excited motor can be employed to raise the power-factor of the circuit.*

Torque Conditions of Synchronous Motor depending upon Angle between Current and Motor E.M.F.

The current flowing in the armature of a synchronous motor may have one of three general phase relations with respect to the motor e.m.f., or E_m. This phase angle may be 180° (Fig. 12A) because *motor* action is here considered, the same relation existing in a D.C. motor; it may be less than 180° (Fig. 12B) or it may be more than 180° (Fig. 12C).

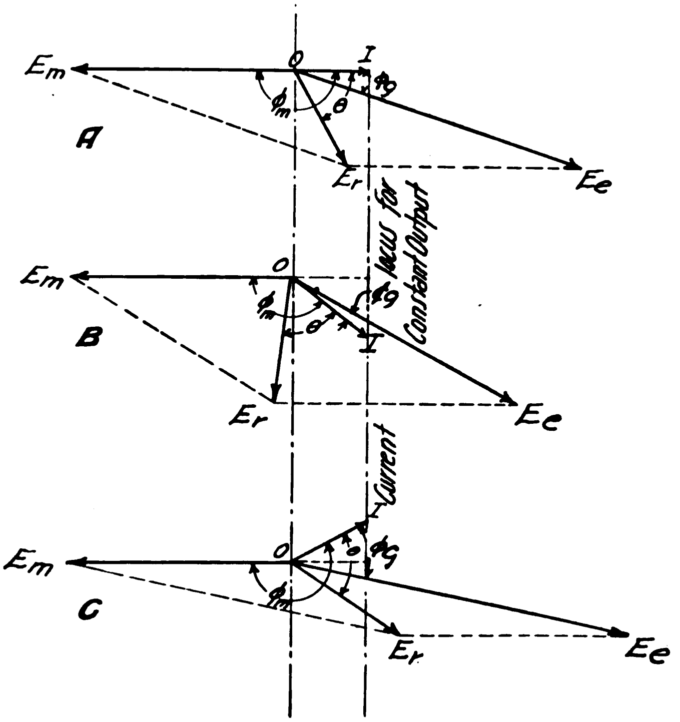

Fig. 12, A, B and C. Various Phase Relations of Motor E. M. F. and Current with Constant Output

The most efficient condition for motor output exists in the first case when the phase angle between E_m and I_a is 180°, since then the current required to produce the desired torque is a minimum. This may be proven as follows: In Fig. 13A, the wave diagrams of current and e.m.f. are shown with a phase displacement of 180°; the resulting power curve P being negative at every instant; thus for a given area (representing motor power) the value of I will be a minimum. This condition is also shown by the equation $E_mI \cos \phi_m =$ motor power; because $\cos \phi_m$ has its maximum negative value $= -1$, when $\phi_m = 180°$, hence to produce a given power with E_m constant I will have minimum value. In Fig. 13B, the wave diagram shows the current displaced less than 180° with respect to motor e.m.f., in which case the resulting power wave has both negative and positive values, hence with a given current the motor power represented by the negative area is not only less than in the preceding case but its effect is still further diminished by the positive area and thus the available motor power is considerably less than when the current and e.m.f. differ by 180°. Therefore, to have the same power the current must be greater in the second case (Fig. 13B). Evidently similar conclusions apply when the current leads the motor e.m.f. as shown in Fig. 13C. An action result occurs when the current and motor e.m.f. differ less or more than 180° in phase; namely a strengthening or weakening of the motor field. For example, if the phase displacement between current and motor e.m.f. is 180°, the current reaches its maximum at the same instant as the e.m.f., which condition is represented by the position of the armature in Fig. 14. In this case the armature current neither magnetizes nor demagnetizes the field, with the moderate flux densities adopted for A.C. machinery. The effect is merely to distort the field, since the *N* poles of the armature increase the flux at the *S* poles of the field and diminish it equally at the *N* field poles—a similar balanced effect being produced by the *S* armature poles.

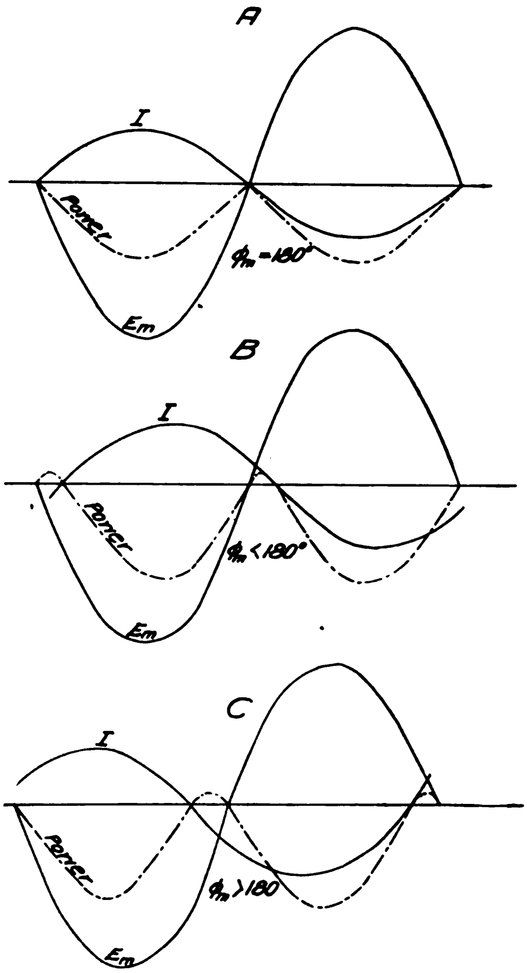

Fig. 13, A, B and C. Power Curves With $\phi_m =, <, >$ 180°

If the armature current lags less than 180° behind the motor e.m.f. it reaches its maximum value at the instant indicated in Fig. 15. An inspection of this diagram shows that the field strength of the motor is increased because the polarity of the armature favors that of the field.

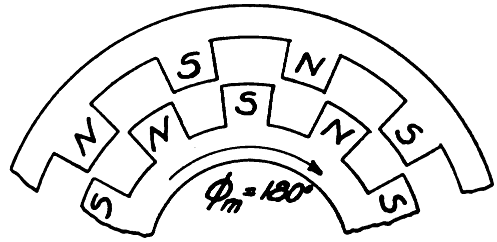

Fig. 14. Angle Between E_m and Line Current is 180° Distortion of Main Field

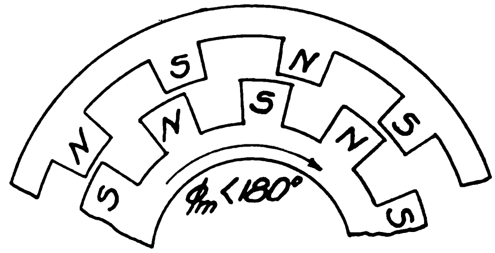

Fig. 15. Angle Between E_m and Line Current less than 180°; Main Field Strengthened

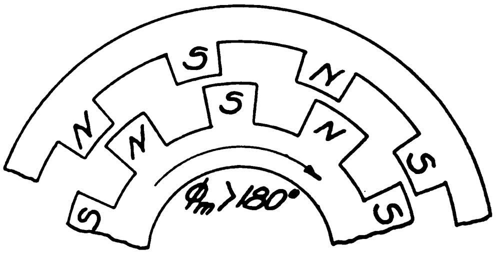

Fig. 16. Angle Between E_m and Line Current more than 180°; Main Line Weakened

If the armature current leads the motor e.m.f., that is, the phase difference is more than 180°, then this current attains its maximum before the armature reaches the position of maximum e.m.f. as shown in Fig. 16.

The result with this phase relation is a weakening of the main field due to the opposition of the armature magnetization, like poles being contiguous.

A summary of the preceding facts is as follows:

1. For a given current a motor develops maximum torque when the phase angle between its e.m.f. (E_m) and the armature current (I) is 180°.
2. When E_m and I differ in phase by more or less than 180° the torque for a given value of I is less than when the phase angle is 180°.
3. When the phase angle ϕ_m is 180° the armature reaction merely distorts the field, because one pole tip is strengthened as much as the other is weakened, with ordinary flux density.
4. When the angle ϕ_m is less than 180°(line current lagging with respect to E_m) the armature reaction strengthens motor field.
5. When the angle ϕ_m is more than 180° (I leading E_m) the armature reaction weakens motor field.
6. The condition of lagging current with respect to motor e.m.f. ($\phi < 180°$) gives more stable operation than the others because the increase of field strength augments the torque of the motor, tending thus to hold it in step.

Conditions of Maximum Output

Various relations between the maximum motor output and the line voltage E_e, the motor constants R, L, and I the motor current can be calculated. But they are only of theoretical interest and that of a low order, because the motor windings would be destroyed long before these conditions could be reached.

For example, a typical 138 kw. synchronous motor has an armature resistance of 0.13 ohm, the voltage across the terminals is 1443 volts, and for theoretical maximum output, the current would be $I = \frac{E}{2R} = \frac{1443}{0.26} =$ 5550 amperes, which is about 55 times its rated load current of 102 amperes, the heating effect being $55^2 = 3025$ times the normal. The corresponding values of maximum watts output and voltage have also been calculated, but the above preposterous result demonstrates that little time should be spent in determining or discussing such imaginary conditions.

(To be Continued)

THERMODYNAMICS

PART IV

BY DR. CHARLES P. STEINMETZ

The three previous articles have discussed the equations of a perfect gas, namely, one in which the molecular distances are large compared to the size of the molecule, and in which the molecular velocity is large compared to the velocity at the boiling point; that is, the molecular velocity at which the liquid changes into gas. When the temperature of a gas is near the temperature of its boiling point, the average velocity of the molecule is only a little more than sufficient to separate the gas molecules and carry them to infinity. Since there is always a considerable range of molecular velocities, some larger and some smaller than the average velocity, it follows that some of the molecules do not separate but condense. Under the latter condition, the volume is less than that required by the first thermodynamic equation, which no longer applies. We have this condition in steam, because, from an engineering standpoint, even when superheated, its temperature is never much above the boiling point. Hence, the first law of gas does not apply, and too great a deviation obtains to be neglected.

For the perfect gas equations to apply, the orbits of the molecules must be strongly hyperbolic, in order that the slowest molecule may have sufficient velocity to be carried out of range. This means that the temperature of the gas must be considerably above the boiling point. At the highest commercial superheats, the steam temperature does not exceed the boiling point by more than 20 to 30 per cent., and the equation $p\,v = R\,T$ no longer holds—$p\,v$ differs from $R\,T$. This difference is zero at a pressure of about 1/10 atmosphere, but rises to 7 per cent. at a pressure of 10 atmospheres.

From the relations which were previously derived between the molecular energy, the intramolecular energy, the position energy, and the external energy at and near the boiling point, the following equation can be obtained for steam:

$$p\,v = R\,T + B - C\,v^{-\frac{1}{3}}$$

A closer agreement with the steam tables, which are themselves approximations, can be obtained by taking the square root of v instead of the cube root. Hence, the equation then reads:

$$\begin{aligned} p\,v &= R\,T + B - C\,v^{-\frac{1}{2}} \\ &= 47.1\,T + 230 - 774\,v^{-\frac{1}{2}} \qquad (8) \end{aligned}$$

As the term $C\,v^{-\frac{1}{2}}$ is small, and the steam tables calculated from empirical equations are based on meagre data, and since also the value of v is somewhat uncertain, it is not possible to decide what exponent of v is the best to use for the last term.

While in the thermodynamics of gas cycles, the use of the term "temperature" gave the simplest expression, the equation just given is too complex for use. In the thermodynamics of steam, the simplest equation is one that avoids the term T. So far as is possible, it is advisable when dealing with steam to use equations which include the terms denoting pressure, volume, moisture or superheat only.

Saturation Curve

At the boiling point, that is, for saturated dry steam, the pressure p_0 and volume v_0 are related by the equation:

$$p_0\,v_0^{e} = \text{const.} \tag{9}$$

which is more conveniently written in the form:

$$p_0\,v_0 = S\,p_0^{i} \tag{10}$$

where:

$$e = 1.064;\quad i = 1 - \frac{1}{e} = .06$$

$$\text{and:}\quad S = 9900 \tag{11}$$

From equation 10 it follows that if the steam contains moisture represented by γ (1 kg. of wet steam includes $[1-\gamma]$ kg. of steam and γ kg. of water), the following equation holds:

$$p\,v = S\,p^{i}\,(1-\gamma) \tag{12}$$

This equation occupies the same position in the thermodynamics of steam as equation (1) for gases.

Superheated Steam

For steam-gas, that is, superheated steam, the adiabatic equation $p\,v^{a_0} = \text{constant}$ applies (13)

$$\text{or:}\quad p\,v = S\,p_0^{i}\left(\frac{p}{p_0}\right)^{c_0} \tag{14}$$

where:

p_0 = pressure at which the steam reaches saturation on the adiabatic curve, and:

$$a_0 = 1.286;\quad c_0 = 1 - \frac{1}{a_0} = 0.222 \tag{15}$$

Suppose now that you are dealing with superheated steam and let it expand to its boiling pressure; the first part of the curve is adiabatic and governed by the equation (14). At a certain point on the curve its character must change, since the temperature cannot drop adiabatically throughout the whole range and only to a point which is limited by the saturation curve. Here the condensation of a part of the steam takes place, and the latent heat of its evaporation keeps the average temperature at the boiling point. As the volume is still further increased, more steam is condensed and evaporated. That is to say, the temperature of the mixture never falls below the temperature of the boiling point.

The adiabatic curve of wet steam is related to the adiabatic constant a_0 of steam gas, the saturation constant e, latent heat S and specific heat c_p by the equation

$$p\,v^{a} = \text{constant} \tag{16}$$

$$\text{or:}\quad p\,v = S\,p_0^{i}\left(\frac{p}{p_0}\right)^{c} \tag{17}$$

$$\frac{1}{a} = \frac{\frac{1}{e} + \frac{m}{a_0}}{1-m} \tag{18}$$

$$m = \frac{S\,p^{i}\left(c_p - \frac{\gamma}{1-\gamma}\right)}{R\,S} \tag{19}$$

where p_0 = the pressure at the point of intersection of the adiabatic and saturation curves. a varies from 1.124 at 1/10 atmosphere to 1.138 at 10 atmospheres pressure, with an average at 1.13

$$c = 1 - \frac{1}{a} = 0.115 \tag{20}$$

The moisture of the steam can be obtained by dividing equation 12 by 17, when we get:

$$\gamma = 1 - \left(\frac{p}{p_0}\right)^{c-i} \tag{21}$$

where: p_0 = saturation pressure, that pressure at which the steam is dried and saturated on the adiabatic curve.

If $p_0 < p$, the steam reached saturation by adiabatic expansion; that is, it is superheated, and γ has a negative value. Superheat appears as negative moisture in this case, and equation 21 gives the equivalence between superheat and moisture.

Energy

The energy or external work done when p_1, v_1 change to p_2, v_2 is $E = \int_1^2 p\,dv$ (22)

Hence for isobaric change $E = p\,(v_2 - v_1)$ (23)

for adiabatic change

$$E = \frac{S}{a-1}\,(1-\gamma_1)\,p_1^{i}\left\{1 - \left(\frac{p_2}{p_1}\right)^{c}\right\} \tag{24}$$

where p_0 = saturation pressure, γ_1 = moisture at initial pressure p_1

Steam Turbine Cycle

$$E = \underset{\text{Admission}}{E_0'} + \underset{\text{Expansion}}{E_{2-1}} + \underset{\text{Exhaust}}{E_{2-0}} \qquad (25)$$

E_0' and E_{2-0} are isobaric (22) and E_{2-1} is adiabatic (24). Hence

$$E = \frac{S}{c}(1-\gamma_1)\, p_1^c \left\{ 1 - \left[\frac{p_2}{p_1}\right]^c \right\} \qquad (26)$$

If during expansion the steam meets with no resistance, its energy is converted into velocity s such that

$$E = \tfrac{1}{2}\, m\, s^2 \qquad (27)$$

Since $m = \frac{w}{g} = \frac{1}{g}$ per kilogramme of steam.

$s = \sqrt{2\, g\, E}$ (28), s being the steam jet velocity.

$g = 9.81$ metres per sec. per sec. (gravitational acceleration).

When calculating the steam jet velocity, it is convenient to introduce the "velocity of expansion into empty space," which is by (28) and (26) for $p_2 = 0$

$$s_0^2 = \frac{2\, g\, S}{c}\,(1-\gamma_1)\, p_1^i \qquad (30)$$

For pressure p_2, $s_2 = s_0\sqrt{1 - \left[\frac{p_2}{p_1}\right]^c}$ (31)

At any intermediate pressure p

$$s = s_0\sqrt{1 - \left[\frac{p}{p_1}\right]^c} \qquad (32)$$

Substituting (30) into (17) we have:

$$v = \frac{c}{2g}\, s_0^2 \left[\frac{p}{p_1}\right]^c p^{-1} \qquad (33)$$

Hence the section of the steam jet—the section of the steam turbine expansion nozzle at pressure p is

$$A = \frac{v}{s} = \frac{c\, s_0}{2g\, p_1\, q^{1-c}\sqrt{1-q^c}} \qquad (34)$$

where $q = \frac{p}{p_1}$ = pressure ratio.

This is a minimum when

$$q = \left[\frac{1-c}{1-\frac{c}{2}}\right]^{\frac{1}{c}} = 0.578 \qquad (36)$$

which means that the minimum nozzle section or nozzle throat occurs at a pressure $p_m = 0.578\, p_1$ equal to 57.8 per cent. of the initial pressure, being independent of the initial pressure p_1 or moisture γ_1.

By substituting (36) in (31), we get the steam velocity in the nozzle throat $s_m = s_0\sqrt{\frac{c}{2-c}} = 0.247\, s_0$ (37) about one-quarter of the expansion velocity into a vacuum.

The steam flow F, or weight of steam in kg. discharged per second through unit area, that is per m^2 of nozzle throat, can be obtained by substituting (36) into (34) giving the nozzle throat section A_m

$F = \frac{0.0527\, p_1^{1-\frac{i}{2}}}{\sqrt{1-\gamma_1}}$ (38) where p_1 is given in kg. per m^2.

Gas Cycle

Following equations (1) to (6) the corresponding equations for the gas cycle are as follows:

$$E = \frac{R\, T_1}{c}\left\{ 1 - \left[\frac{p_2}{p_1}\right]^c \right\} \qquad (26)$$

$$s_0^2 = \frac{2g\, R\, T_1}{c} \qquad (30)$$

$$v = R\, T_1 \left[\frac{p}{p_1}\right]^c p^{-1} \qquad (33)$$

$$F = \frac{0.988\, p_1}{\sqrt{T_1}} \qquad (38)$$

If the numerical values for air are substituted, we get $p_m = 0.528\, p_1$ and $s_m = 0.408 s_0$

For a monotonic gas,, as argon or mercury vapor, $p_m = 0.487\, p_1$, $s_m = 0.5\, s_0$.

Numerical Values of Steam Turbine Cycle

For saturated steam at p_1 = 12 kg. cm²
= 170 lbs. sq. inch
the energy of expansion into vacuo = 173,500 kg. m.
the jet velocity = 1845 m. per sec.
= 6050 ft. per sec.

Thus the jet has a velocity of over 4000 miles per hour, sufficient to cross the Atlantic in one hour.

Energy of expansion to pressure p_2 = 0.07 kg. cm²
= 1 lb. per sq. inch
is 77,400 kg. m.
the jet velocity = 1236 m. per sec.
= 4060 ft. per sec.

With four successive expansion steps (stages) each utilizing one-quarter of the total energy from $p_1 = 12$ to $p_2 = 0.07$, that is from 170 lbs. to 1 lb. pressure per square inch.

The energy per stage is 20,000 kg. m.
Jet velocity = 630 m. per sec.
= 2060 ft. per sec.

The largeness of these velocities explains the difficulties which had to be overcome in the development of the steam turbine, since the velocity of the rotor of a steam turbine must be about one-half the jet velocity used by it in the impulse type, and equal to it in the reaction type; for maximum efficiency.

(To be Concluded)

RECENT DEVELOPMENTS IN TRANSFORMING APPARATUS*

By H. W. Tobey

In the following article, an attempt will be made to outline as concisely as possible a few of the developments in transforming devices which have taken place during the past year.

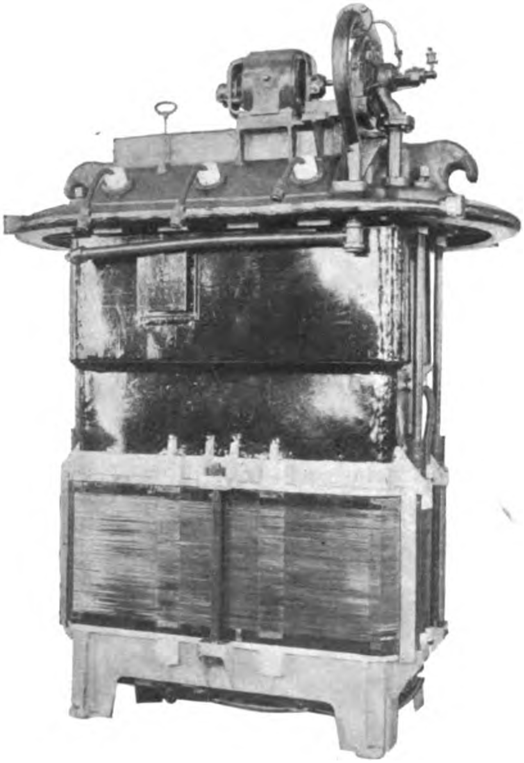

Fig. 1. Forced Oil Transformer Removed From Case

Some of these are perhaps already familiar, while others may present new ideas or well-known principles applied in new ways. At all events, it is hoped that a brief review of the work may prove of some interest.

Naturally the first subject which suggests itself is the one which deals with some of the largest apparatus built, so that a short review will be given of the steps which lead up to the later designs, with special reference to features which make the building of large transformers possible.

The Forced Oil Transformer

When oil first came into general use a few years ago for the purpose of insulating and cooling, transformers were comparatively small in size and the surface of coils and core was comparatively large in proportion to the quantity of heat to be dissipated. The natural circulation of the oil, therefore, due to difference in heat at top and bottom of containing tank, was sufficient to maintain the proper temperature. As the size of transforming apparatus increased, it became necessary to provide additional tank surface in the shape of corrugations or veins; in order not only to radiate the increased amount of heat, but also to maintain such a difference in temperature between the upper and lower portions of the oil as to cause its more rapid circulation. After a time even this arrangement proved inadequate, and it became necessary to resort to other means. This time an internal water cooling coil was introduced, and by its means a still further difference in heat potential was created, which resulted naturally in a more rapid transfer of heat. In all these designs, it should be noted that the natural circulation of oil is relied upon to convey heat from the coils and interior of the transformer to the outer cooling surface.

The size of units continuing to increase, the amount of heat to be dissipated likewise became greater, and the seat of its generation more and more remote from cooling surfaces. The next step, then, was to assist the natural circulation of oil, and this resulted in what we call today the forced-oil type of transformer. This provided a means of rapidly transferring heat from the inner portion of core and coils to the outside, where it could be readily taken care of.

Several advantages resulted. With the increased circulation all parts of the coils and core were maintained at a more uniform temperature, those at the top being little warmer than those at the bottom. This feature also made it possible to transfer a greater quantity of heat to the oil than before, and further than this, heat pockets were eliminated. As a result of these advantages, the radiation constants could be increased, and the amount of active material proportionately decreased. Thus it has been possible with this type of construction to considerably reduce the cost of the transformer, provided the size of the unit is large enough and the voltage not too great in proportion to the kilowatt rating.

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* Paper read before the Schenectady Section of the American Institute Electrical Engineers.

More will be said upon this point later. On the other hand, the use of additional auxiliary apparatus is required in the way of pumps, coolers, etc., which tends somewhat to offset this saving, and, in fact, does offset it where the combined capacity of the individual units is much less than 5000 kw. For equipments larger than this, it is always well to consider the forced oil design.

Mention has already been made of the size of the unit and the voltage as affecting the adoption of forced oil circulation. The reasons are apparent from the following. For transformers of comparatively small capacities and high voltages, the size of the conductor and dimensions of the coils must be such as to give the required mechanical safety and ruggedness. In other words, the conductor and coils are made as small as safety will allow. It is manifest then that nothing would be accomplished by resorting to mechanical circulation. With these considerations in mind, it is usually found inadvisable to make this type in sizes of less than 1200 to 1500 kw.

In equipments already designed and built, the practice has been to employ two complete sets of cooling and circulating apparatus, one to be used as a spare in case of the failure of the other. Each consists of a pump for circulating the oil, a surface condenser or cooler, and a pump for circulating the water; all of these being suitably connected to the transformer by means of delivery and return pipes.

This type of transformer is similar to the standard water cooled type without the cooling coil. Provision is made, however, for the uniform distribution of incoming oil by enclosing the lower part of the coils with a metal box fitted with baffle plates. Oil is led into this chamber by means of a vertical pipe passing down through the cover. The outlet is placed somewhat above the top of the coils and considerably below the surface of the oil, so that there will be no danger of uncovering the former, and so that no air will be drawn into the system.

For large plants, this arrangement of having a cooling system common to a number of transformers is working admirably. There are now installed and in successful operation at the Great Northern Power Company's plant in Duluth, Minn., six 7500 kw. 60 cycle, 60,000 volt forced oil transformers, making a total of 45,000 kw.; and another equipment of 1500 and 1667 kw. of the same type at the Kern River Plant, Los. Angeles, Cal., aggregating over 41,000 kw. The Whitney Power Company has also been furnished with ten 1667 kw. of this same design, making altogether a total of over 102,000 kw.

In some plants where the conditions are suitable, it has been thought advisable to adopt individual coolers and separate oil circulating pumps and motors. For example, in the case of the equipment for McCall's Ferry which when installed will consist of six 5000 kw. Type FO units, the waters in the tailrace pass in close proximity to the transformers, and advantage was taken of this feature by specifying individual coolers to be placed in the tailrace, where the circulating oil can be efficiently cooled without resorting to any auxiliary water circulating devices. In addition to this each unit will be provided with its own oil pump and motor, making it entirely separate from the others. With this arrangement, any trouble occurring in one transformer, due perhaps to moisture or breakdown, cannot be communicated to other units in the same equipment, a contingency which is not so easy to provide against in the design previously mentioned. Moreover, any transformer can be removed or a new one installed without in the least interfering with the others.

There are some plants, however, where conditions preclude the use of individual condensers or coolers—certain steam power plants, for example, or water power plants where the tailrace is remote from the transformer house. To provide for such conditions, therefore, a new type of forced oil apparatus has been developed which is entirely self-contained. Even the external cooler is done away with, so that the equipment is still more flexible than one of the McCall's Ferry type just described. In this apparatus the cooling coil is placed inside the tank, as in the water cooled type, except that its convolutions extend nearly to the bottom. A cylindrical or elliptical metal casing, depending upon the contour of the tank, separates this coil from the main oil chamber, with the exception of one or more openings at the bottom. By means of an individual motor and circulating pump mounted on the cover (Fig.1) or in close proximity to the transformer, the oil is pumped out at the top of the central chamber and into the space inclosing the cooling coil. The static head caused by the resulting difference in level thus greatly increases the natural oil circulation through the coils and core. The result is an outfit of extremely simple design, which, on account of its self-contained features, is as flexible as one of the ordinary water cooled type. It embodies the same features as the forced oil equipments already built, and at the same time absolutely prevents troubles in one unit from spreading to the others.

An equipment consisting of two 3000 kw. transformers of this description is soon to be put in service at the General Electric Works, Schenectady, and in addition to this two 5000 kw. units are being built for the Chicago Edison Company. Before passing from this subject, it might be well to add a word or two as to the actual temperatures of oil and water, and to compare the operation of the forced oil type with that of the ordinary water cooled or oil cooled design.

It is customary in forced oil apparatus to circulate sufficient water to carry away the heat with a rise in temperature of the water of approximately 10 degrees. If the temperature of the incoming water, then, is 15 degrees, that of the outgoing will be 25 degrees. This usually requires about 1/3 of a gallon per minute per kilowatt loss in the transformer. Approximately the same temperature rise is allowed in the oil so that the greatest difference in oil temperature between the bottom and top of the tank is not far from 10 degrees. The specific heat of oil is a little less than one-half that of water, therefore its theoretical rate of flow would be approximately double. Practice bears this out except that in some cases it is found advisable to increase the flow of oil to 3 or 3½ times that of the water. In any case, however, the flow of water and oil should be so adjusted as to avoid chilling the latter and retarding its circulation.

From the foregoing, it will be evident that, as the size of transformers increased, the natural tendency has been to provide means of increasing the rate of flow of the cooling oil. If we assume this rate equivalent to one, in the self-cooled type, it will be between two and three times this in the ordinary water cooled design; while with the forced oil type of transformer the rate of circulation by artificial means will be increased from three to four times that of the self-cooled type.

Few perhaps realize the actual rate at which oil circulates in the various types of transformers, and we are quite apt to think of the flow as extremely sluggish. It might be of interest, therefore, to cite a concrete example. Take for instance, the 7500 kw. FOT type built for the Great Northern Company. In these, the oil circulates at the rate of 100 gallons per minute, while the calculated flow through the various coils and core channels is something like 30 ft. per minute. Based on these figures, which were obtained from actual measurements, together with results obtained from water cooled transformers designed for a similar temperature rise, the rate of oil flow is probably not far from 50 gallons per minute for a 7500 kw. unit of the WC type; while the oil must pass through the various ducts at the rate of 15 ft. per minute. Even the natural circulation, due to difference in temperature alone, is not so slow then as is sometimes imagined.

Experience with Oil Filled Leads

We have now heard something of the development of transformers of large capacity. Not only has the demand for apparatus of large size steadily increased, but with it the demand for increased voltage; so that while a few years ago the requirements were for apparatus of not over 10,000 or 12,000 volts, today they are more nearly ten times these values. This has made it necessary to design and build for operating voltages of 100,000 and over, and in some instances for test values of over 300,000 volts.

While the design of transformers, the internal parts of which would meet these requirements, was difficult enough, the problem of bringing out the high tension leads was one which required perhaps fully as much consideration.

It has been customary with apparatus of moderate voltage, to rely on leads insulated with wrappings of tape, together with the additional protection afforded by porcelain bushings. For still higher voltages, greater insulation was obtained by putting on more tape and resorting to larger porcelain parts. And to prevent surface leakage from end of terminals to case, the lead was either made very long or was provided with a number of circular barriers or discs.

It became extremely difficult and expensive, however, to use this design for apparatus of 70,000 or 80,000 volts—which required test values of double this amount—and as oil had proven itself an excellent insulating medium for internal construction, the idea occurred to utilize it for external parts as well. The problem was then to provide a suitable structure for holding the oil.

The first oil filled lead put into service was made up of a series of resin filled circular wooden sections mounted one on top of the next with pressboard collars between. In later patterns, moulded compound was substituted for the wood and the oil space inside was broken up into several sections by pressboard tubes extending the entire length of the lead. Openings at top and bottom of these tubes allow for ready filling with oil and for circulation.

With this design, the distance from the end terminal to the body of the lead next to the case is usually about 50% greater than the natural voltage jumping distance for which the lead is designed, while the length of the creepage path is rendered about three times this amount by the presence of the pressboard discs.

What the final limit of this type of lead will be, we do not yet know. It has already been used successfully on commercial apparatus requiring tests of somewhat over 300,000 volts, and investigations are being made, the results of which, it is believed, will enable us to reach voltages very much higher than this.

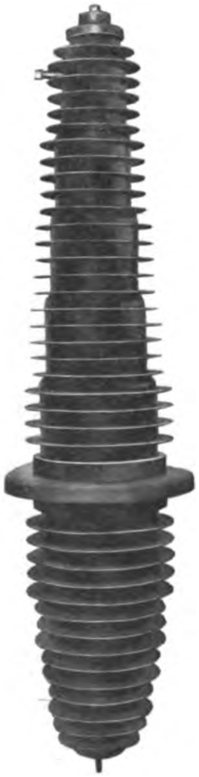

Fig. 2. High Tension Oil Filled Bushing

One of the desirable features of this type is the ability to distribute the electrostatic strain. This perhaps as much as anything else has rendered it particularly useful, as any lead which allows concentrated strain at one point is always in danger of ultimately breaking down. Moreover, the oil in the various internal tubes is free to circulate and thus prevent local heating. The general appearance of the lead is shown in Fig. 2.

Not only has it been used to good advantage in power transformers of high voltage, but also in the construction of certain types of series transformers where again the problem of bringing out high tension leads required careful consideration. Before taking up this phase of the subject, however, it will be well to consider the development of the series transformer up to the point where the oil filled lead became a necessary adjunct.

Development of the Series Transformer

Going back into history for a moment it is interesting to note that the series transformer was first used in connection with a street lighting system. Its use in this connection, however, was a failure, and for 15 to 20 years it played little or no part in electrical work. Then as the demand grew for a device which would give comparatively small current values directly proportional to the larger currents flowing in a line, it again came into commercial use in connection with measuring instruments.

At this time, however, it was in no way considered a protective device, and although it gave an accuracy in ratio which was compatible with the accuracy of the measuring instruments of the period, no attention was paid to refinements of ratio-transformation and phase displacement. As its use became more general, and the accuracy of the instruments improved, the demand for a more accurate device increased, and with the introduction of higher voltages better insulation was required, insulation that would protect not only the instruments but also the operator.

At that time it was considered essential, in order to keep the magnetizing current within reasonable limits compared with the accuracy of transformation, to use a magnetic circuit without joints. This naturally resulted in the adoption of a core built up of sheet iron rings. The primary and secondary windings were then placed on this core, it being necessary to wind them entirely by hand, the conductors being threaded through the central opening. The secondary, or instrument winding, was usually placed next to the core. Then came the insulation, put on in the form of tape, and finally the primary winding.

To be sure, this process was somewhat expensive, but for small sizes and comparatively low voltages it gave very satisfactory results. It is still used successfully where tests as high as 20,000 and 25,000 volts are required.

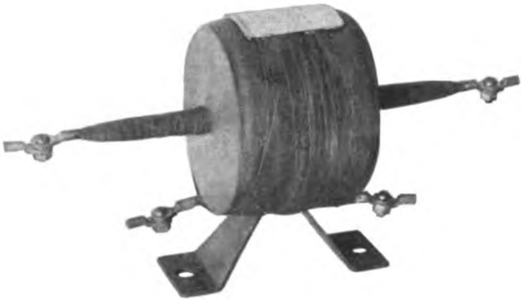

Fig. 3. Early Type of Series Transformer

For voltages higher than this, the insulation became a serious problem. The number of tapings had to be increased, which meant time and expense, and even after they were once in place it was difficult to take care of the heat from the windings unless this had been rendered very low by the use of conductors of large cross section. To overcome the necessity of using an extensive number of tapings, a new type was developed in which the low voltage secondary was wound on the core as above, while the insulating medium consisted of telescoping tubes, held apart by suitable spacing strips. Part of these were slipped through the inside of the ring and part over the outside, which arrangement provided ample insulation for direct break between primary and secondary near the central part of winding. In order to obtain sufficient creeping surfaces between primary and secondary, where the former passed over the latter, it was necessary to extend the tubes to a considerable distance on either side of the core, to fill in the space with discs of porous material, and then give the whole device a vacuum compound treatment. This treatment served not only to make the transformer moisture proof, but also added greatly to the insulating value of the leakage surface between coils. The result was a transformer which satisfactorily withstood a considerably higher test voltage and gave good results, although it was somewhat bulky and expensive.

Up to about three years ago it was considered sufficient to insulate the series transformer with the same margin of safety that was allowed in potential transformers, *i.e.*, double the line voltage. Owing to several reasons, however, it was deemed advisable to require an insulation test of three times that of the operating circuit. In the first place, the secondary of a series transformer is usually grounded, and, being the first thing in the path of a lightning discharge, often receives the entire blow and acts in the capacity of a lightning arrester. Moreover, it furnishes current not only to the measuring instruments but also for the various limiting and protecting devices; therefore, it is often the keynote, so to speak, of the whole switchboard equipment. The fact, too, that the safety of the attendants depends on the insulation of this piece of apparatus, makes the triple voltage ruling doubly important. It meant, however, the addition to the standard line of a transformer for 15,000 volt circuits which would withstand an insulation test of 50,000 volts. One was naturally developed along the lines previously described. The result, however, was a transformer which, while it met all requirements successfully, was one of rather large dimensions, expensive construction, and which required—due to the method of insulation—a rather long time for production.

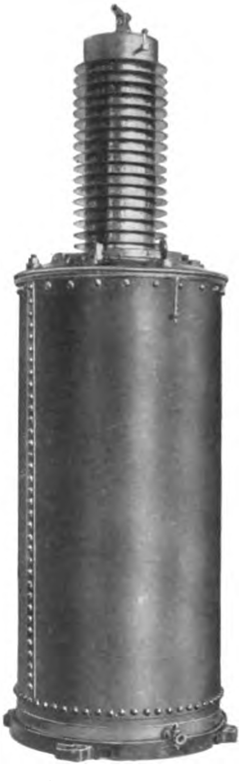

Fig. 4. Latest Type of Series Transformer, for Operation on 100,000 Volt Circuit

Consequently, time and thought were put into the development of a new type that would lend itself more readily to high voltages, and at the same time would be less expensive and would require less time for production.

It is evident that the methods used for the insulation of a transformer built on a core without magnetic joints, were the only ones which appear at all practicable. In consequence, in considering the development of a new type, it became necessary to investigate the use of a core having one or more joints, it having been previously felt that those of the jointless type were cheaper to build. Contrary to belief, however, it was found that a design could be developed by using a core having joints, which not only would be cheaper but at the same time more accurate than those previously constructed.

When these points were proved, it was natural to utilize the U-shaped punchings which had been so long in successful use in the construction of the core type transformer. This then resulted in the adoption of form wound coils, the secondary and primary being wound separately and receiving enough varnish taping to stand the required test voltage. The coils were then assembled on one leg of the core, with the secondary next to the iron and the primary slipped over it, the core being suitably clamped to the frame, which furnished support for the secondary terminals and feet for the mounting of the device as a whole. The resulting transformer had many advantages over the older type, but still left things to be desired, the most prominent of which was shortening of the time required for production.

About this time great strides were being made in the use of moulded insulation, and the idea occurred to utilize such material in connection with high voltage series transformers, by moulding it completely around the primary coils. This was accomplished only after many trials, for it should be remembered that not only must the compound be a good insulator electrically, but a good heat conductor, mechanically strong and must be built to withstand repeated expansion and contraction. It must also be capable of being formed around the coil at not too high a temperature, otherwise the cotton covering of the conductor would be ruined. In addition to these requirements, the preparation must not soften at operating temperatures, and must not be too expensive. In spite of these numerous conditions, a compound meeting them all was developed.

During the first attempts to use this compound, the enclosing casing was moulded in halves, these being placed around the coil and sealed together. During test, however, weakness developed at the joints and this form was abandoned. The arrangement finally adopted, which is now being successfully used, consists of a complete compound ring, the sides of which are open at the top. The primary coil is placed in this ring and the open sides are folded over and forced together under a pressure of somewhat over two tons per square inch, at a temperature of about 200°C.

The result is a coil with suitable leading out terminals, enclosed in an insulating casing without a single joint or seam. It readily withstands a test of 50,000 volts, and in fact will not break down at much less than 80,000. This then results in a series transformer which is absolutely safe on 15,000 volt circuits, is neat in appearance, less expensive to build, and requires a much shorter time to produce.

In passing, it is interesting to compare the length of time consumed in insulating coils with tape, using the original method, with that required to produce a coil insulated as just described. The first method necessitates the use of many layers of tape, each having a number of varnish treatments, and the total time required for insulating is over twenty days. The new method requires thirty minutes.

Up to this point we have considered the use of dry types only requiring tests as high as 50,000 volts. On general principles, however, it would be preferable to resort to oil much below this point; but this has not been considered advisable, owing to the strong preference to avoid its use in switchboard construction.

Oil is used, however, for all transformers requiring a pressure test of over 50,000 volts. The arrangement of coils and core in this type is somewhat similar to that previously described for the lower voltage dry type using ring punchings. The usual practice is to wind the secondary directly on the core and to provide a number of tubular barriers, nested one within the other, with oil spaces between for insulation, the primary being threaded through as already mentioned. This construction, combined with the oil filled lead previously described, has been used successfully for apparatus requiring tests as high as 300,000 volts. (See Fig. 4).

(To be Continued)

THE SCHAGHTICOKE-SCHENECTADY TRANSMISSION LINE OF THE SCHENECTADY POWER COMPANY

By John Liston

This transmission line carries practically the entire output of the Schaghticoke power house (described in the April Review), to Schenectady, N. Y., a distance of approximately 21 miles. (Fig. 1.)

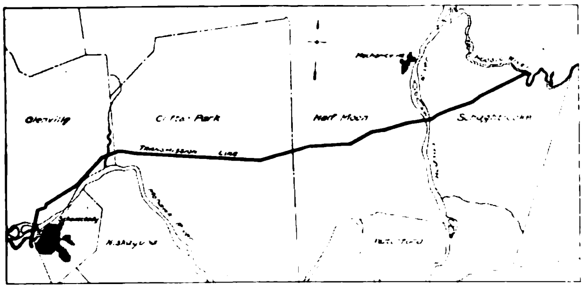

Fig. 1. Course of the Transmission Line

The line consists of two separate three-phase, 40 cycle, 32,000 volt circuits, each of 6000 kw. normal capacity. These circuits start from opposite ends of the power house, and, after crossing the Hoosic River, are transferred by means of two terminal towers (Fig. 2) to a single line of transmission towers. On these the two circuits are carried on opposite ends of the cross arms, the three phases being superimposed.

The power house ends of the line are held by six short quadrangular steel lattice-work anchor poles with their bases firmly imbedded in concrete, the cables being dead-ended by General Electric disk strain insulators. This equipment, together with the lightning arrester horn gaps and the heavy line outlet insulators mounted on the roof of the power house, is shown in Fig. 3.

While each circuit carries only 6000 kw. under normal conditions, either is capable of carrying the entire output of the station; in this case, however, the line losses are necessarily augmented. This feature prevents any interruption of the service from the failure of one of the circuits and fully justifies the expense incurred in running what are practically duplicate lines.

There are altogether 197 transmission towers, comprising several distinct types, some of which are shown in the accompanying illustrations. These may be classified as follows: standard, terminal, standard angle, special railroad crossing, Mohawk River, and transposition towers. All types except the terminal towers are quadrangular in form, and all are symmetrically built up of structural steel. With the exception of three special towers crossing the New York Central Railroad, all towers are galvanized finished; the special railroad towers being coated with graphite paint.

The substantial construction of these towers is indicated by the following outline of dimensions: The height from the ground line to the bottom cross arm of a standard tower is 51 ft.; the distance between cross arms 10 ft., and from the upper cross arm to the peak of the tower, 5 ft.; making the total height from ground line to peak 76 ft. The distance between the two circuits on the cross arms is about 17 ft. and the base is 17 ft. square.

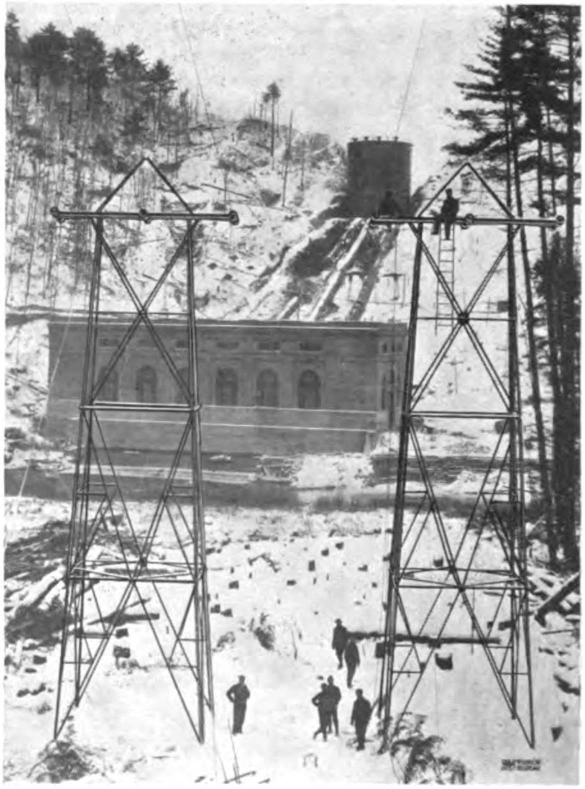

Fig. 2. Beginning of the Transmission Line showing Transfer Towers with Power House in Background

In the transposition towers, as in the standard type (Fig. 5), the lower arm is approximately 17 ft. wide, while the upper arm is a trifle over 28 ft. wide and is supplied with metallic braces which extend from a point midway between the insulators to the base of the peak.

The phases are in vertical relation, and in making a transposition, the center phase is first shifted in the direction of the pole, the upper phase is brought to the bottom, the middle phase to the top, and the bottom phase to the center arm. Each transposition tower gives one-third of a rotation, the six towers of this type accomplishing two complete transpositions between Schaghticoke and Schenectady.

The line passes for the most part through a sparsely settled country; but where it crosses railroad tracks, or at those points where a break in the line might endanger life, the towers are provided with grounded metallic guard arms. These are shown on the towers in Figs. 6 and 11. When nearing Schenectady, the line passes over a considerable extent of low flat country, and also across the Mohawk River. At this point three special towers have been constructed, similar in general form to the standard towers, but having a total height of 96 ft. from ground line to peak, the distance to the bottom arm being 70½ ft.

The increased height of these towers was rendered necessary by the requirements of the state engineers, which call for liberal clearance at every point where the transmission cables cross the line of the prospective New York State barge canal.

Where the soil is firm, no special foundations have been used for standard towers. They are bolted to and rest on metal stubs which are firmly imbedded in the ground. In any tower, however, where the line changes its course by an angle of over two degrees, these stubs are weighted with sufficient concrete to withstand the overturning effect of cable strain and maximum estimated wind pressure. In towers on tangents this precaution is not necessary, as the rigidity insured by the design eliminates all danger of overturning.

Wherever the line makes an angle of less than 10 deg., standard towers have been used, while for angles of 10 deg. and over, angle towers with strain insulators are employed. In cases, however, where the combined curvature of the line and the contour of the ground had a tendency to drag the cables of one circuit in the direction of the tower arms, strain insulators have been used on standard towers.

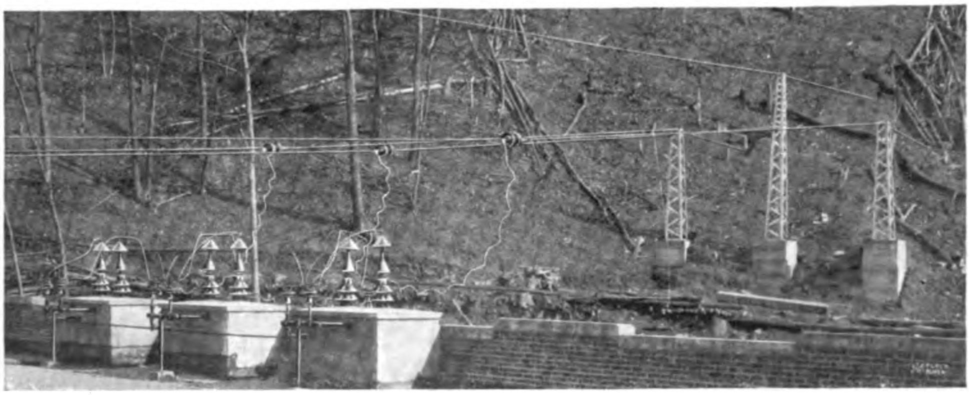

Fig. 3. View from roof of Power House, showing Anchor Poles, Strain Insulators, Lightning Arrester Horn Gaps and Line Entrance Bushings

While temporary guy wires have been used on many of the towers during construction, they will all be removed after the line has weathered one season and the soil of the foundations has properly settled.

Angle towers, which are naturally subjected to great torsional strains, are all erected on massive concrete foundations, each leg having a separate concrete pier. These angle towers are illustrated in Fig. 7, and are similar in construction to the standard towers, having the same general vertical dimensions but with bases 20 ft. square. They are also made throughout of heavier material.

In the towers crossing the flat lands and islands of the Mohawk River, the concrete foundations are extended up the tower on each leg to a point beyond high water mark, so as to eliminate danger of injury by ice or floods.

In constructing the transmission line, the various portions of the towers were transported to the different foundation sites and then assembled, the numerous sections being securely bolted together and the completed structure lifted into position by means of a special portable "A" frame.

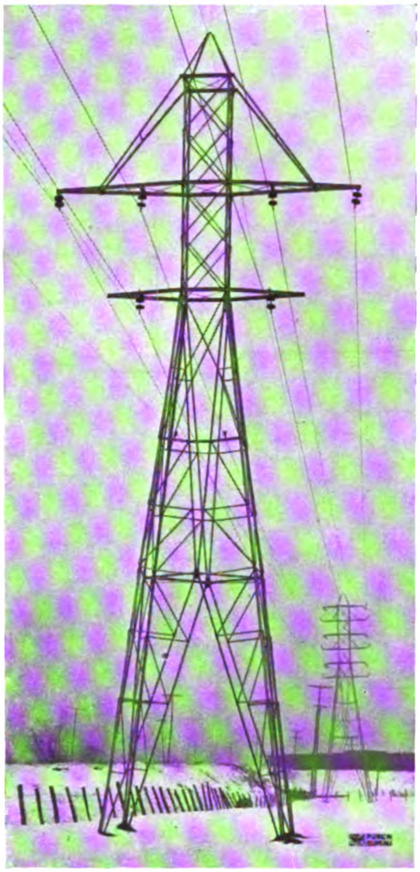

Fig. 4. Transposition Tower

The only exception to this practice occurred in the construction of the New York Central railroad crossing towers, which were riveted and built up instead of being erected complete.

To those interested in the details of transmission line construction, the following description of the methods used in stringing the cable and securing a uniform stress factor throughout the line may be of value.

The cable was received in lengths of about 2000 ft., wound on reels, and every precaution was taken to prevent injuring it during installation. Hard drawn copper wire has its densest, and therefore its strongest, portion at the surface, the core of the wire being relatively weak; in stringing it, therefore, it is important to see that no abrasion or pinching occurs to diminish its tensile strength.

Prior to running the cables, linemen were sent ahead and attached snatch blocks provided with wooden rollers to the arms of the towers. The six cables were then strung out loosely through these snatch blocks, and one end of each cable was firmly anchored by means of a special wooden clamp, 6 ft. in length, to the first tower. The necessary tension was then applied to the cable between the first and second towers, and a dynamometer used to indicate when the required stress point had been reached. The cable was then anchored to the second tower and the operation repeated for the different spans. The ends of the cable were then

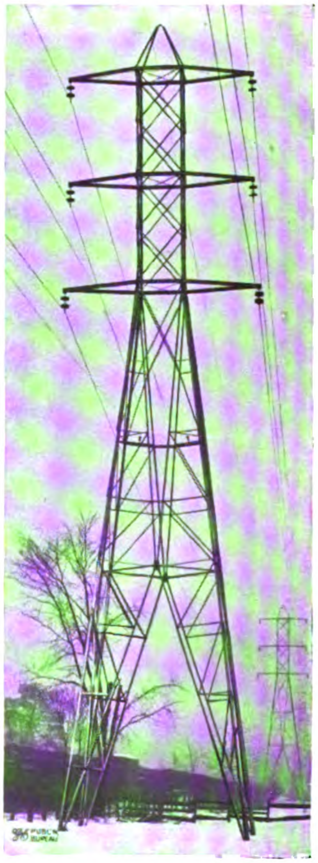

Fig. 5. Standard Tower

anchored, as before, to the last tower with wooden clamps, and the cables on the towers back of it transferred to the insulator clamps.

The ordinary practice in stringing transmission cables is to allow a definite amount of sag or dip between adjacent towers or poles, the amount of sag depending upon the length of span and the difference, if any, in the level of the towers. The vertex of the cable in each span is then lined up with a given point or points on the towers. For transmission lines strung at a relatively low tension, this method, which is called "sighting in the line," is both simple and effective. Many of the factors, however, which go to make up the total strain on the line, and are considered negligible in a line of low stress, are of great importance when the cables are strung at high tension.

In running the cables on the Schaghticoke-Schenectady transmission line, the following points were kept in mind in determining the proper tension for the different spans: the distance between towers, the variation of tower level, the temperature, and the pounds pull at the insulators. The linemen were supplied with three carefully plotted sets of curves which enabled them to check their work as follows: The first curve gave the vertical deflection of the cable for varying lengths of span, between towers at the same or different levels; the location of the vertex of any span could thus be readily determined. The second set was used in combination with the first, and gave the variation in the sag for any given length of span at temperatures varying from −40° F. to 110° F. The third set gave the tension in pounds at the insulator at varying temperatures and lengths of span. These curves were used throughout in combination with simultaneous dynamometer and temperature readings, to obtain a tightly strung line with an ample factor of safety under the severest weather conditions; giving at the same time

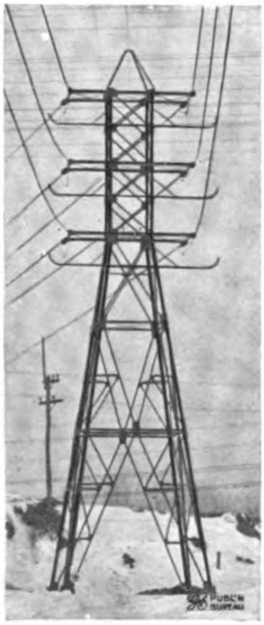

Fig. 6. New York Central Railroad Crossing Tower, provided with Grounded Guard Arms

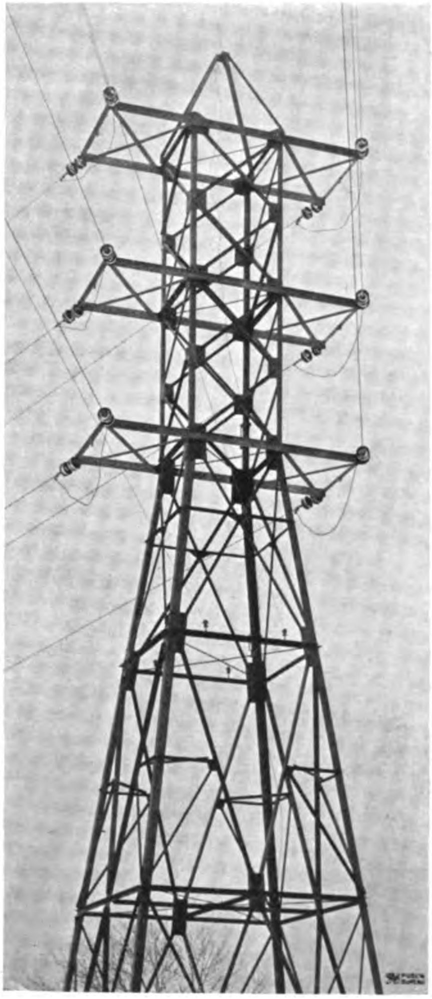

Fig. 7. Angle Tower showing G.E. Strain Insulators

the closest possible approach to a uniform stress on the different towers.

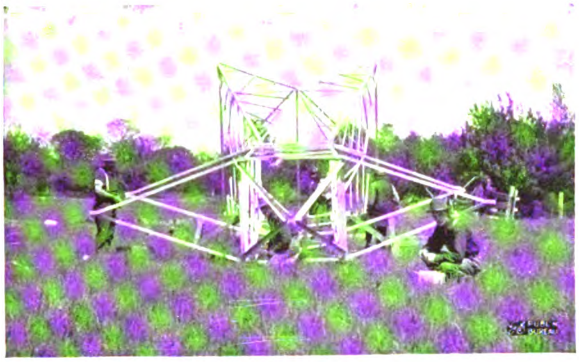

Fig. 8. Standard Tower under construction

In order to avoid unduly complicating these curves they were plotted for a condition of "no wind."

In order to avoid pinching the cable at towers where strain insulators were used, an ingenious contactor clamp was designed. It is made of malleable iron with galvanized finish, and contains an "S" shaped groove, through which the cable is run. This groove provides a maximum friction contact surface, and only a small bolted lug is required at one end to positively prevent the cable from slipping.

A simple wrapped splice has been used throughout for joining the cable ends, as experiments carried on with patent tubular splices were not satisfactory, owing to the high tension at which the line was strung. No trouble whatever has been experienced with the wrapped splice.

The use of screws, bolts and nuts has been avoided wherever possible, so as to minimize the danger of parts becoming loose when subjected to vibration.

Owing to the irregular contour of the country through which the line passes, the spacing of the towers varies within wide limits. The standard span is 600 ft., but other spans range all the way from 150 ft. to 1263 ft. in length, the latter distance being required where the line crosses Sanders Lake, situated near Schenectady. Where the line crosses the Hudson River the span length is 1125 ft., and, in spite of the fact that there were no available hills near the banks of the river and that the State barge canal calls for a clearance of 29.3 ft. above normal low water, the line was carried across on standard angle towers. However, in order to obtain the required clearance, it was necessary to increase the tension at which the cables were strung to about 3000 pounds per cable.; the average tension of the cables throughout the line being approximately 2300 pounds.

Where the length of any span is considerably in excess of the standard 600 ft. (except in the special instances already mentioned), towers have been used in which the standard form of construction is retained, but in which heavier structural material is used.

Prior to the beginning of construction work, and in order to determine fully the factor of safety afforded by the design of the towers under the severest conditions, a special test tower was erected and subjected to numerous torsion tests which were far in excess of any strain the transmission towers would have to withstand in normal service.

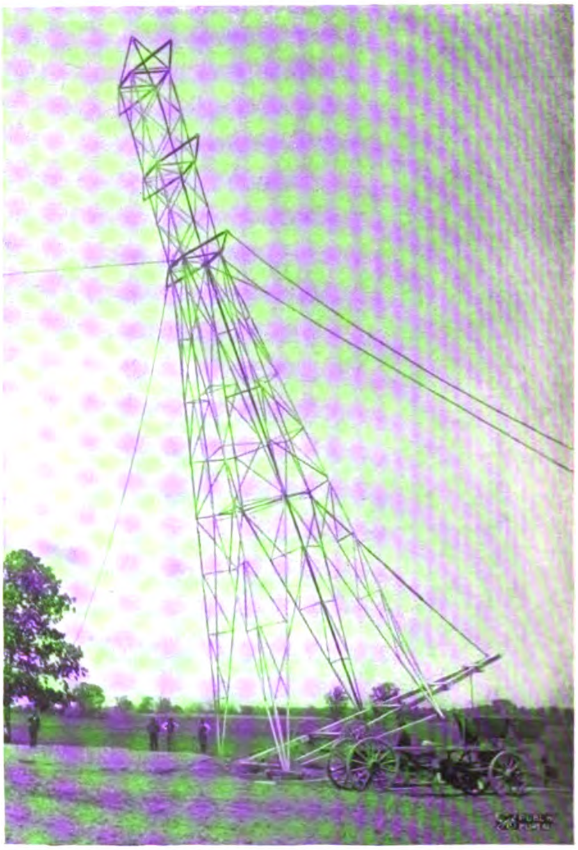

Fig. 9. Lifting the Tower into position with Portable "A" Frame

The total weight of steel in the towers of the transmission line, including the structural material for the telephone circuit, such as bolts., etc., is approximately 900,000 pounds.

The towers carry six conductors, each conductor consisting of a No. 000 seven-strand hard drawn copper cable weighing 0.53 pounds per ft. and having an elastic limit of 35,000 pounds per square inch, with a coefficient of elasticity of 12,000,000. The temperature coefficient of linear expansion is 0.000009 per degree Fahrenheit, and the normal operating temperature range was estimated at from −40 deg. F. to 110 deg. F.

In designing the transmission line an extreme wind velocity of 85 miles per hour on the bare cable was assumed, or 40 miles per hour on the cable when coated with 1/4 in. sleet. Under these conditions, when strung on the towers, the cable would have to withstand a stress of 4600 pounds, the normal operating tension, as stated above, being 2300 pounds. The cable has a breaking strength of 7500 pounds and is a product of the Wire and Cable Department of the General Electric Co.

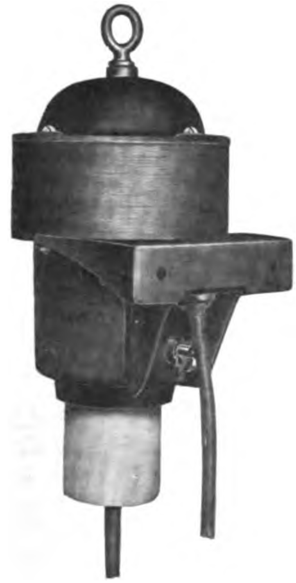

Fig. 10. Telephone Line Insulating Transformer

Running along the tops of the towers and firmly clamped to each peak is a lightning guard wire made of Siemens-Martin 3/8 in. stranded steel. It is worthy of note that this guard wire is grounded at every tower and that up to date it has proven very effective in protecting the line from dangerous lightning discharges. Any surges that take place in the line itself are taken care of by two aluminum lightning arrester equipments, one of which is located in the power house and the other at the receiving station at Schenectady.

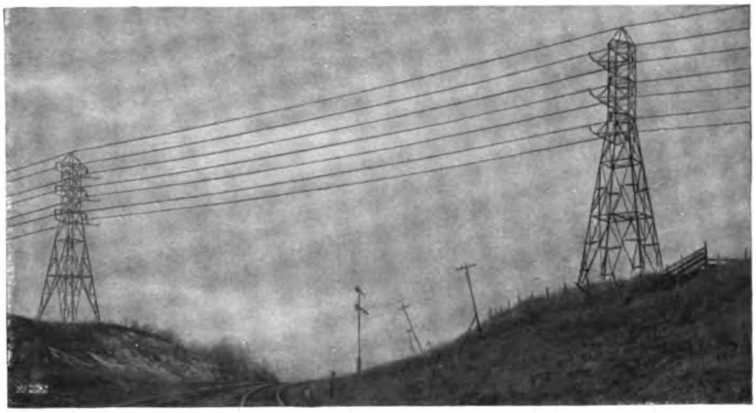

Fig. 11. Line crossing the tracks of the Boston & Maine Railroad near Schaghticoke. This illustration shows the tension at which the line is strung

In many transmission lines the question of a lightning guard wire has been an after consideration, but the structural form of these towers indicates clearly that the question of effective lightning protection was provided for at the very start and made a definite portion of the construction as originally designed.

The insulation of the transmission line on both standard and strain towers is provided for by means of General Electric disk insulators. The lacing of these insulators consists of cable made of copper coated steel wire, and when two or more insulators are connected in series, the lacings are joined by means of drop forged steel links. The use of cement has been altogether avoided in their construction, the bodies of the insulators being made from one solid piece of selected porcelain.

For each transmission cable two of these insulators are suspended in series. The strain insulators are connected two in series, and while they are of the same general form as the suspension type, are made somewhat heavier to withstand the increased strain to which they are necessarily subjected.

Three line patrolmen are kept constantly on duty, and the entire line is inspected every day. Telephone wires are run the full length of the line and the patrolmen are provided with portable telephone instruments. At 12 stations transformers are connected between the telephone wires and the instrument wires, so as to afford ample protection from static. The construction of this telephone line is unusual, due to the fact that it passes from tower to tower without intermediate support. This fact necessitated its being strung under considerable tension, and it was therefore necessary to utilize strain insulators on each tower. In order to avoid the possibility of breakage in the line itself, No. 6 galvanized iron wire was used. To counteract the induction effects, the telephone line has also been transposed, but unlike the power lines, transposition occurs at every tower.

The telephone line insulating transformer used in this installation is a special type recently developed and placed on the market by the General Electric Company. (Fig.10.) It is designed for use on telephone systems in connection with high voltage transmission lines. It safeguards the users of telephones from the danger of high voltage, due either to induction or accidental contact between the telephone and the power lines, where the lines are on the same pole or on parallel adjacent poles. These transformers are all given very thorough high potential tests between windings to insure the greatest safety.

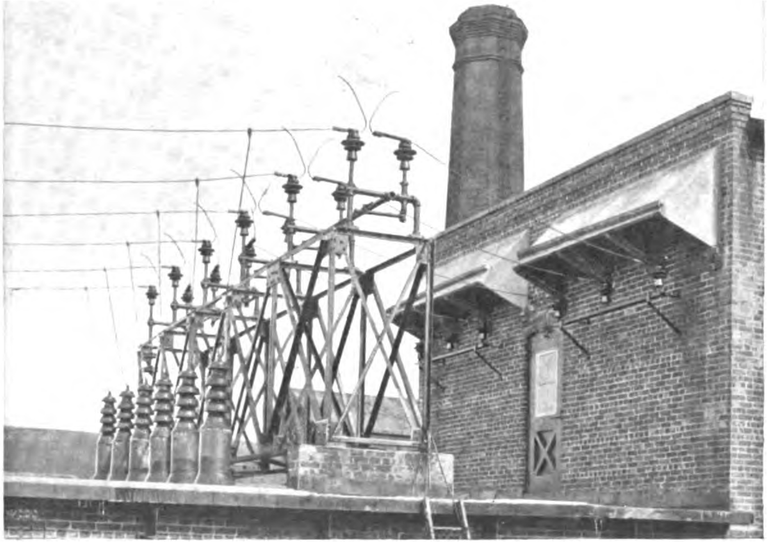

Fig. 12. The end of the line at Schenectady, showing Line Entrance Bushings and Lightning Arrester Horn Gaps

The transformer is assembled in a weather-proof iron case so that it can be readily installed out of doors. So efficient is this device that if the telephone lines are well insulated and the instruments are separated from the line by means of these transformers, the service can be continued over the telephone line, even if there should be a cross with the high-tension system.

As soon as the construction work on the transmission line was completed, the entire equipment was subjected for several hours to a double voltage test, 60,000 volts being impressed at the power house end. During the time that this test was in progress the line was carefully patrolled, and in order to more readily detect defective insulation, the test was conducted at night, since any action due to static or sparking over would then immediately become apparent to the patrolmen. This test was conducted under the supervision of Messrs. Viele, Blackwell & Buck, Consulting Engineers, New York City, who designed and constructed the transmission line.

While this transmission line is not unusual, either in length or capacity, it is a very effective example of careful design, symmetrical appearance, and thorough construction, and embodies to an unusual extent all those features which experience has demonstrated as necessary to uninterrupted and efficient service.

SKIN EFFECT

PART II

By W. E. Miller

Resistance

The heating of a solid conductor is given by the formula $\frac{l\sigma}{2}\int_0^r i^2 dr$ where σ is the specific resistance, i the maximum current in each layer, r the radius of the layer, and l the length of the conductor. Since the heating is independent of the phase relations between the currents in different layers, this formula can be written:

$$\frac{l\sigma}{2}\int_0^r i^2 dr = \frac{2\pi l\sigma s_c^2}{2}\int_0^r r\ (ber^2 q + bei^2 q)\, dr =$$

$$\frac{l s_c^2 q}{8\pi k^2 \mu n}\ (ber\ q\ bei'q - ber'q\ bei\ q) \qquad (8)$$

where s_c is the maximum current density at the center. Since the total current (root mean square) equals $\frac{r s_c}{2\sqrt{\mu k n}}\sqrt{ber'^2 q + bei'^2 q}$ and since the resistance equals $\frac{heating}{current\ squared}$ $= R$.

$$R = \frac{lq}{2\pi r^2 k}\ \frac{ber\ q\ bei'q - ber'q\ bei\ q}{ber'^2 q + bei'^2 q} \qquad (9)$$

Now the resistance of a cylindrical conductor with uniform current distribution is $\frac{l}{\pi r^2 k}$, or $\frac{l\sigma}{\pi r^2} = R_u$

$$\text{hence } R = \frac{q}{2}\ \frac{ber\ q\ bei'q - ber'q\ bei\ q}{ber'^2 q + bei'^2 q}\ R_u \qquad (10)$$

Curve Fig. 7 gives the ratio of $\frac{R}{R_u}$ for values of q from 0 to 20. From $q = 0$ to $q = 1.5$, practically no increase of resistance occurs.

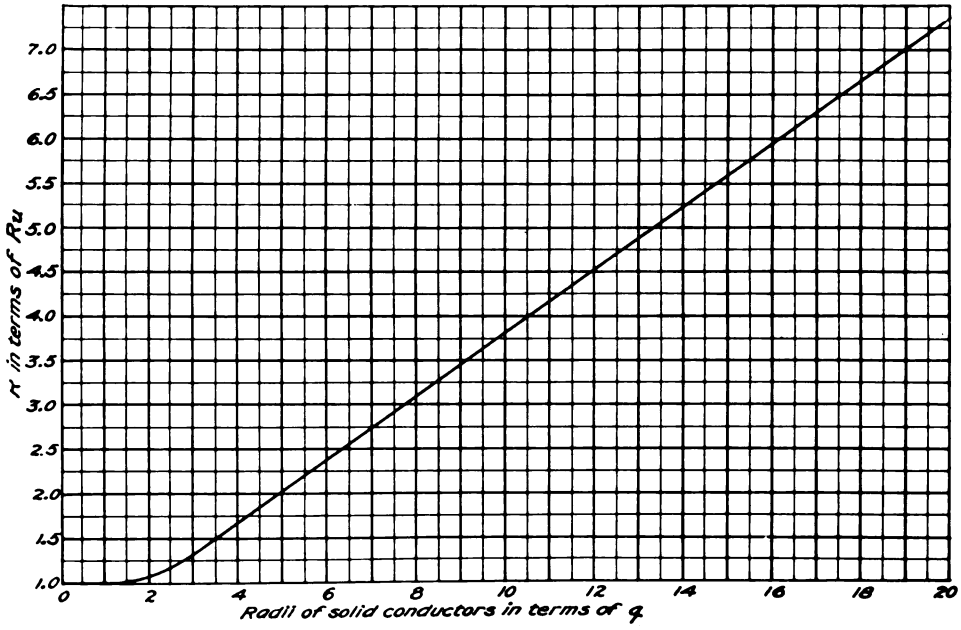

Fig. 7.

For copper at 25 cycles, $q = 1.5$ corresponds to a conductor 1.1 inches in diameter, with an increase of resistance of 2.5 per cent.; and at 60 cycles, to a conductor 0.70 inches in diameter. Hence, even at the higher frequency, skin effect does not alter the resistance of copper conductors of which the diameters are less than about three quarters of an inch. Above $q = 4$ the curve is practically straight; that is, the ratio of the resistance with and without skin effect increases nearly proportionally to q, or to the diameter of the conductor for a given frequency.

The quantity $\frac{ber\, q\, bei'q - ber'q\, bei\, q}{ber'^2q + bei'^2q}$ approaches nearer and nearer to the limiting value $\frac{1}{\sqrt{2}} = 0.707$, as q increases in value.

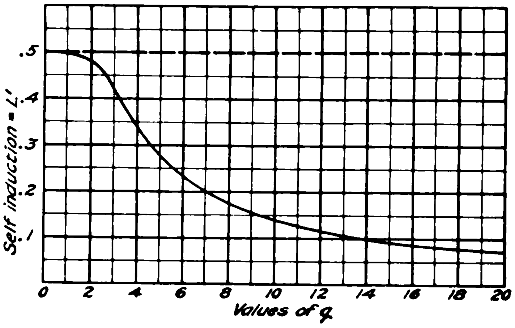

Fig. 8.

Consequently, for very large conductors or very high frequencies, the resistance formula reduces to

$$R = \frac{q}{2\sqrt{2}} R_u = \pi r \sqrt{k\mu n}\, R_u = \frac{l}{r} \sqrt{\frac{\mu n}{k}} \qquad (11)$$

Hence in such cases the resistance is inversely proportional to the radius or surface of the conductor and not inversely to the square of the radius, as obtains with uniform distribution of current. This means that, at a constant depth below the surface of a conductor, the current always falls to a definite fraction of the total current; the depth being independent of the size of the conductor, provided the frequency, conductivity and permeability are kept constant. Thus, as will be seen later, for conductors corresponding to values of $q = 20$ or larger, the current density falls to about one-tenth of its surface value in a depth represented by $q = 3.4$, and to one-hundredth of its value at a depth represented by $q = 6.8$.

Since q varies directly as the diameter of a conductor, and as the square root of the conductivity for a given frequency and permeability, it follows that if the diameters of two conductors made of different conducting materials are proportioned so that their total resistances for uniform current distribution are the same, the increase of resistance due to skin effect will be equal in the two cases. Hence, so far as skin effect is concerned, for a given heating loss at a given frequency and permeability, no advantage is gained by choosing one conducting material rather than another. This was pointed out at the beginning of the article. In some cases, however, a conductor of larger radius has an advantage over one of smaller radius, because of the larger surface area presented for heat dissipation.

For long spans on transmission lines, it is now sometimes the practice to use steel stranded cable. In such cases skin effect cannot be neglected. The increase of resistance of the stranded cable due to skin effect may be taken to be equal to that obtaining with a solid cable of the same sectional area since, although the external diameter of the stranded cable is increased, its active surface is also increased, and therefore the increase of resistance should not be greatly altered. For a seven strand cable, q should be calculated on the basis of an external diameter about 13 per cent. less than the external diameter of the cable.

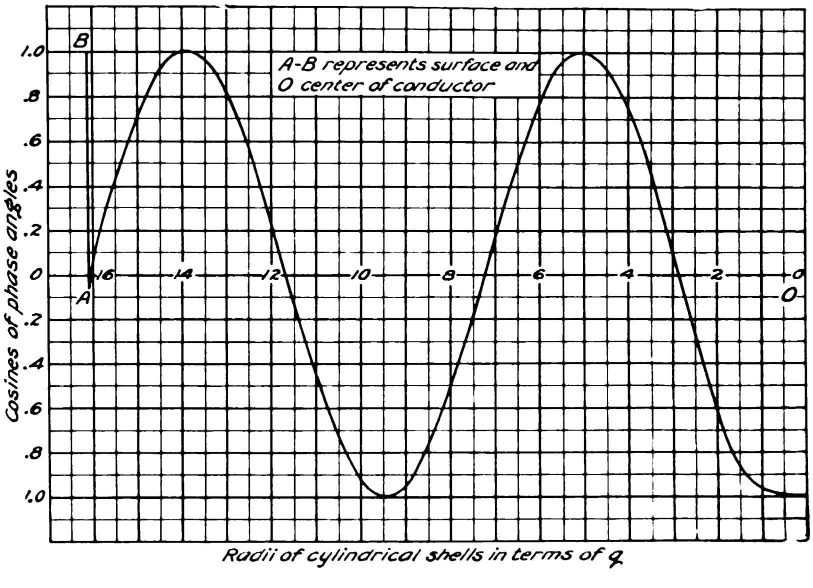

Fig. 9.

If the external diameter of a seven strand cable is ¾ in., μ being taken as 400 and σ 8 times its value for copper, the value of q can be taken as 6.5 for the increase-of-resistance effect, for a frequency of 25 cycles per second. Hence, the resistance of the steel stranded cable will be increased 2.55 times due to skin effect in this case.

Self-Induction

Considering the conductor as existing by itself, the value of the self-induction is expressed by the formula

$$L = l\left(\frac{2\mu}{q}\,\frac{ber\,q\;ber'q + bei\,q\;bei'q}{ber'^2q + bei'^2q} + A\right)$$

$$= l\,(L' + A) \qquad (12)$$

where A is a constant, depending on the induction outside the conductor; that is to say, A is proportional to the induction in the space external to the conductor, due to the current in the conductor. It is independent of the current distribution inside the conductor. The first term in the equation represents the induction due to the current, in the space occupied by the conductor. For uniform current distribution this term is equal to $\frac{\mu}{2}$.

The curve Fig. 8 is plotted for non magnetic substances and shows how the variable part of the self-induction decreases with increasing values of q. For $q = 20$ its value has fallen to 0.07, or about $\frac{1}{7}$ of the value that obtains with uniform distribution.

It decreases slowly with still higher values of q, becoming vanishingly small at very large values.

For large values of q (high frequencies, large conductors, etc.) the term L′ approaches the limiting value $\frac{\mu\sqrt{2}}{q}$, hence the reactance inside the conductor in such cases is equal to

$$lpL' = \frac{l}{r}\sqrt{\frac{n\mu}{k}} \qquad (13)$$

It therefore has the same value as the resistance given in formula (11).

In estimating the proper value of μ which should be chosen in any given problem, it must be remembered that although for low current densities, as high a value as 1000 can be assumed; where skin effect is of importance the concentration of flux at the surface may saturate the iron and consequently reduce the permeability. If the conductor is stranded, the reluctance of the magnetic circuit is increased, which will also reduce the average value of μ through the conductor. Hence, in the seven strand steel cable already discussed, the value 400 may be too large.

The total self-induction of a circuit using stranded wire is slightly less than that of one using solid wire of the same cross section and slightly greater than that of one using solid wire of equal diameter, constant current density being assumed throughout the conductors. In such cases the self-induction can be approximated to by assuming it to have a value greater than the value of the induction with solid wires of equal external diameter by an amount which is ⅔ the difference between the induction with solid wires of equal section and the induction with wires of equal diameter. To take care of skin effect with reference to the induction due to the conductor regarded as existing by itself, assume it to have a diameter corresponding to a solid conductor of equal cross section and calculate q on this basis.

Electro-motive Force

The electro-motive force E is connected with the current flowing by an equation similar to that obtained for uniform current distribution in the conductor $E\ sin\ pt = RI + L\frac{dI}{dt}$, R and L having assigned to them the values already found in formulæ (9) and (12). The current can then be written

$$I = \frac{E}{\sqrt{R^2 + p^2L^2}}\ sin\left(pt - tan^{-1}\frac{Lp}{R}\right) \text{ where } p = 2\pi nt.$$

The impedance $\sqrt{R^2 + p^2L^2}$ is practically unaffected by the decrease of L due to skin effect, because the greater part of the self-induction in most cases is outside the conductor and independent of the current distribution. Since R increases as the square root of the frequency and, practically speaking, the total circuit reactance pL as the frequency, it is clear that for high frequencies the reactance is in general the more important; consequently the increase of impedance does not differ very much from that which obtains with uniform current distribution. The energy loss for a given current is, however, increased considerably, *viz.*, proportionally to the increase of resistance. Thus for $q = 20$ the resistance is 7.3 times the resistance with uniform current distribution; hence I^2R is also 7.3 times as great. For equal *IR* voltage drop, the current is $\frac{1}{7.3}$ as large; and, since the resistance is 7.3 times as great, the heating in this case is $\frac{1}{7.3}$ times as great as the heating in a conductor with uniform current distribution.

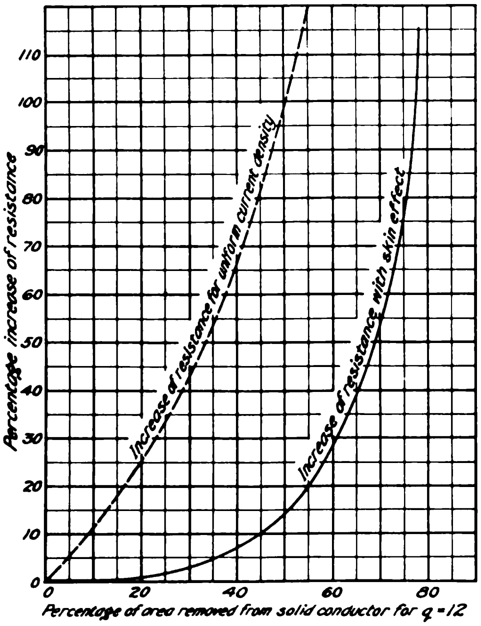

Fig. 10.

Phase Relations

The phase change between currents in different layers is given by formula (3) $\phi = tan^{-1} \frac{bei\ q.}{ber\ q}$ For large values of q, the change of phase angle is nearly constant from the surface inwards, being approximately 40° for each layer of thickness q penetrated. Hence the curve Fig. 9 connecting q with $cos\ \phi$ will closely follow a harmonic curve, except near the center of the conductor where the phase angles between successive layers change more slowly. The curve has been plotted connecting q with $cos\ \phi$ for a conductor of which the outside radius is 16 in terms of q. It will be noticed that a complete reversal of phase (360°) has occurred at a depth represented by $q = 9$, nearly. It so happens that the current density in the center has a maximum negative value when the surface current density is zero; but this is only due to the particular value of q chosen for illustration.

Hollow Conductors

The concentration of the current in the surface layers of a conductor proves that some of the material of the conductor core can be removed without appreciably increasing the resistance. Since in some cases the saving of material is considerable, it is of practical value to discover how much can be removed without increasing the resistance by more than a certain definite amount.

If the core to be taken out carries but a small percentage of the total current, the shape of the current distribution curve in the remaining part of the conductor will only be slightly altered by its removal. The curves Figs. 11, 12, 13 and 14 have been plotted on this assumption. The removal of the core will make the shape of the current distribution curve actually less steep; hence the resistance of the hollow conductors as calculated below are rather too large and, as a consequence, the assumption made is on the safe side. Formulæ 5 and 8, giving respectively the total current and the heating in a conductor, can be readily applied to calculate the increase of resistance resulting from the removal of part of the conductor.

If i_0 is the current in the core and i that in the whole conductor; h_0 the heating of the core and h the total heating; when the core is removed the heating of the remaining conducting zone, for the same total current through the conductor, is increased in the ratio $\frac{i^2}{(i-i_0)^2} \cdot \frac{h-h_0}{h}$; hence the resistance is increased in this ratio also.

Although curve Fig. 10 cannot be regarded as accurate for much greater increases of resistance than 20 per cent., it has been drawn to illustrate the great advantage of cutting out the inside portion of a conductor in which the skin effect is large ($q = 12$). A similar curve for uniform current distribution is also plotted for comparison. In the first curve mentioned it will be noted that 45 per cent. of the cross section can be removed without increasing the resistance more than 10 per cent., whereas with uniform current distribution, the increase of resistance is over 80 per cent.

Curves Figs. 11 and 12 give the radii of the cores that can be removed from conductors $q = 0$ to $q = 20$ and $q = 20$ to $q = 200$, with a resulting increase of resistance of 10 per cent. The five per cent. isoresistance line has also been drawn for conductors up to $q = 20$. The depth, in terms of q, to which the current penetrates the conductor in order to make the resistance of the conducting shell equal to that of the whole conductor increased by 10 per cent., is given in these curves.

It will be noticed that this penetration becomes practically constant in conductors corresponding to $q = 12$, the limiting value of the penetration for very large values of q being slightly greater than $q = 4$. Hence for a large conductor, or for very high frequencies, the depth of penetration is small and constant, and is independent of the diameter of the conductor for a given frequency and permeability. For example, the resistance of a conductor ($q = 100$) will only be increased 10 per cent. if a core of radius ($q = 96$) is removed; this corresponds to an area 92½ per cent. of the total area of the conductor. For an increase of resistance of one per cent., the penetration for values of q above 16 is, $q = 7.7$ approximately; thus a core of radius $q = 92.3$, or an area slightly greater than 85 per cent. of the total cross section of the conductor, can be removed without increasing the resistance more than one per cent.

The dotted lines correspond to similar curves in the case of uniform current distribution. Here the depths of penetration and the core radii that can be removed, are directly proportional to the radii of the conductors; hence they are straight lines passing through the origin and coinciding with the corresponding curves for non-uniform distribution up to $q = 4$, nearly.

Curves Figs. 13 and 14 give the percentage areas that can be removed for an increase of resistance of 1 per cent., 5 per cent. and 10 per cent., for values of q, $q = 0$ to $q = 20$, and $q = 20$ to $q = 200$. The dotted lines correspond to uniform distribution of current. The 1 per cent. isoresistance line does not depart appreciably from that corresponding to uniform distribution until $q = 5$ is reached, $q = 4$ being the departure point for the 10 per cent. isoresistance line. At $q = 200$, as much as 92 per cent. of the area can be removed without altering the resistance more than one per cent.

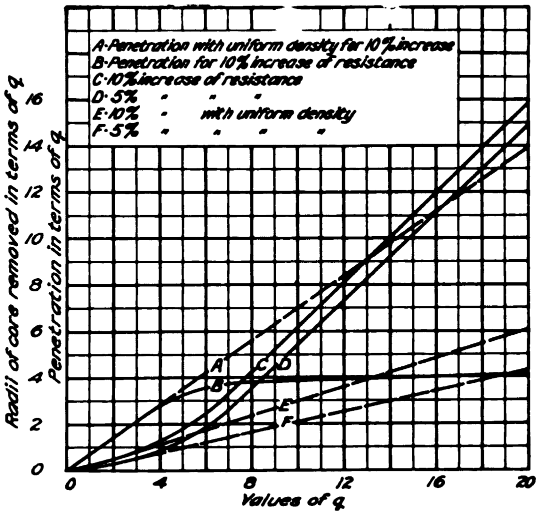

Fig. 11.

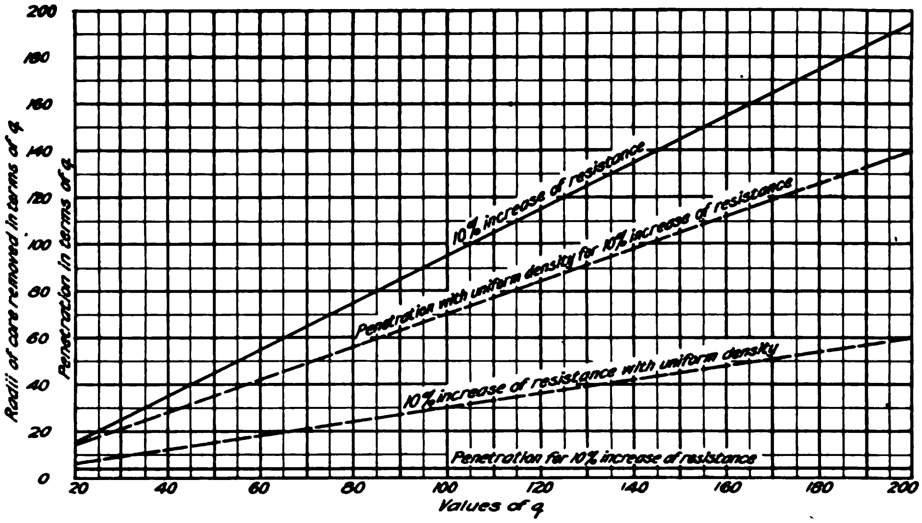

Fig. 12.

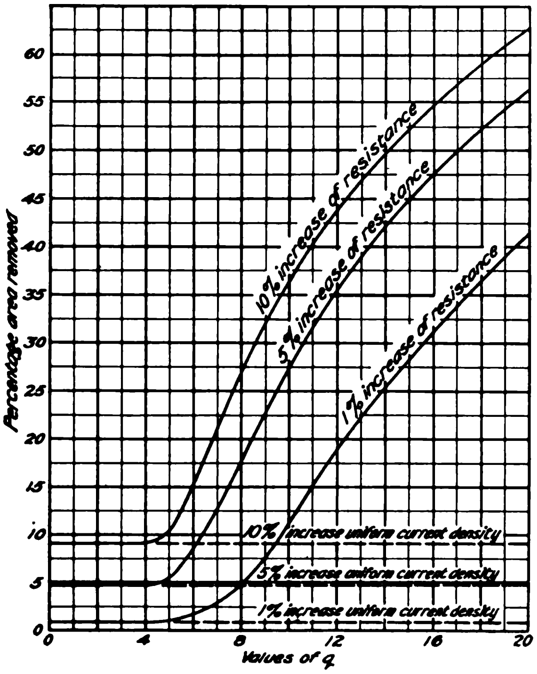

Fig. 13

The above curves have been plotted for large values of q in order to include copper conductors varying in diameter, say from ½ inch to one inch, at frequencies from 10,000 to 1,000,000 per second; these conditions occurring in earth returns for lightning arresters. For instance, suppose the diameter of a copper conductor is ¾ in., then

$$q = \frac{8.86 \times .75 \times 2.54}{2} \sqrt{\frac{250,000}{1620}} = 105$$

for a frequency of 250,000 per second. At a frequency of 1,000,000 per second, $q = 200$ corresponds to a diameter of 0.72 inches.

Since the resistance for these high values of q is $\frac{q}{2\sqrt{2}}$ times the resistance that obtains with very slow alternations (uniform current density), for $q = 105$ it is equal to $\frac{105}{2.83}$; that is, 37 times as great. This resistance is only altered one per cent. if 86 per cent. of the core is removed, whereas with uniform current density through the conductor, the removal of this amount of material would increase the resistance over 7 times. Hence in this case the resistance of the hollow conductor at high frequency is only a little greater than 5 times its resistance for uniform distribution.

The conceptions which flow from these considerations are of considerable interest. Amongst others, the opacity of conducting materials to light naturally suggests itself. The frequency of light is of the order 10^{15} per second, and hence the effect of conductor curvature can be neglected unless wires of thinness approaching atomic dimensions are considered. The penetration formulæ can, therefore, be applied to flat surfaces, say a thin copper sheet. In order to form an estimate of the depth of penetration of light through a copper sheet, let us suppose that the current is completely stopped within a depth represented by $q = 7$, at which depth the current density has fallen to less than 1/100 of its value at the surface. We may imagine, therefore, that this thickness represents the minimum thickness necessary for completely reflecting the light. If d is this thickness in inches, we have

$$8.86 \times 2.54\, d \sqrt{\frac{10^{15}}{1620}} = 7,$$

hence $d = 4.10^{-7}$ inches.

For gold the penetration would be 1.15 times as great. In this connection, it may be of interest to note that Faraday is stated to have obtained gold leaf only 10^{-7} in. thick.

This thickness is a small fraction of a wave length, and as it is probably only about 100 molecules thick, it is doubtful if the laws of conduction and diffusion hold. The calculation is merely given to indicate the kind of result that may be expected. If the order of the result is at all near the truth, it suggests that, in the phenomenon of reflection from polished metallic surfaces, practically only the surface atoms are affected; hence, a rhythmic and regular vibration is possible and but little of the energy is dissipated into irregular modes of vibration, or in other words, into heat. The efficiencies of reflection from such surfaces should therefore be high. However interesting these speculations may be, they would lead too far afield and are hardly proper to the subject matter or scope of this article.

Penetration with Uniform Current Density giving Equivalent Resistance

Since it has been shown that only a small and constant depth of conductor is penetrated with high frequencies (large values of q), it is of interest to find what thickness of conductor shell, in which the current density is uniform,

will give a resistance equal to the resistance of a solid conductor of the same external diameter taking skin effect into account. If r is the outside radius of a conductor shell and x its thickness, the resistance of the shell with uniform current density will practically be $\frac{r}{2x}$ times the resistance of the solid conductor. Hence, to find x we have $\frac{q}{2\sqrt{2}} = \frac{r}{2x}$; therefore $x = \frac{r\sqrt{2}}{q} = \frac{1}{2\pi\sqrt{\mu k n}}$ (14)
The penetration is thus independent of the diameter of the conductor, and a little less than one-fifth of the penetration into the conductor with skin effect which gives a resistance increase of 1 per cent.

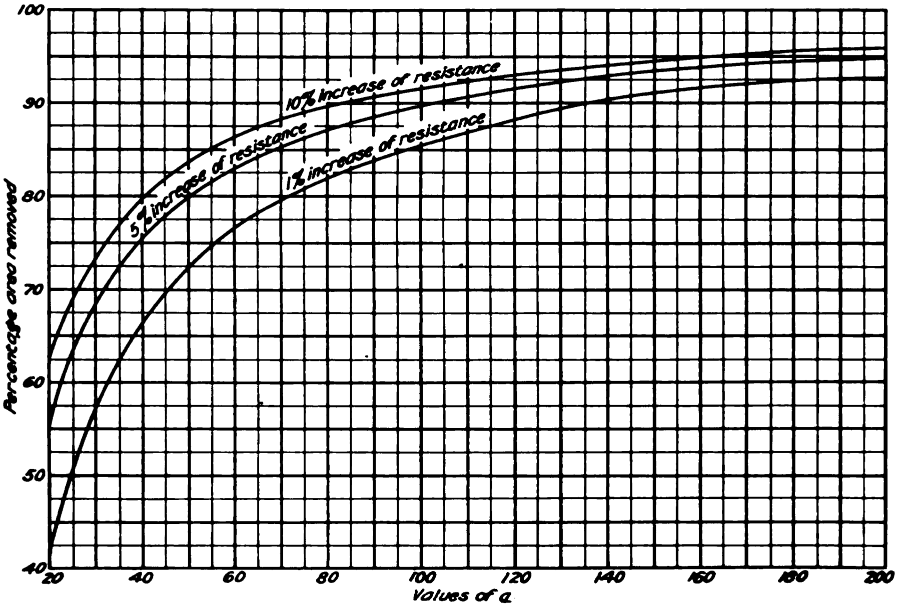

Fig. 14.

Shielding

The amount of penetration calculated, say for a resistance increase of one per cent., shows that the conductor core below this depth is completely shielded by the inductive effect of its own current. Hence, conductors carrying current in the same phase should not be placed too close together. If three conductors are in close proximity, the central one may practically be entirely shielded from the impressed electro-motive force, and as a consequence carry no current; it is copper wasted. If the phases are mixed, the shielding of one conductor by another is eliminated, and, since the reactance is also reduced, this arrangement would seem most economical.

Shape of Conductor

The effectiveness of large conductors for heavy currents depends on the amount of their active surface. Hence, to economize space, conductors may be made approximately rectangular in shape, with a breadth considerably greater than depth.

Return Conductor

As already mentioned in the beginning of this article, the formulæ given neglect the effect of the return or other conductors carrying current, and hence are only directly applicable in a few cases. The mutual induction between two conductors carrying currents in opposite directions concentrates the current along their adjacent sides; that is, the induction due to the current in one conductor tends to increase the current in the other on that half nearest to it, and to reduce the current in the half remote from it. Hence, an unsymmetrical distribution of current results on each conductor. The value of the induction due to one conductor is not constant through the space occupied by the other, but varies approximately inversely as the distance from the center of the first conductor.

Hence for both reasons, a greater skin effect will be produced than that calculated from the formulæ, and a greater increase of resistance will result.

If the two adjacent conductors are carrying current in the same direction, an opposite effect will result; that is, concentration will occur on those parts of the two conductors remote from one another, and the nearer parts will have less current—they will be shielded. In this case, the induction due to one conductor will exert its opposing effect to the greatest extent on those parts of the other conductor nearest to it; this effect decreasing the deeper the latter is penetrated. After crossing the current axis, the induction will still decrease in magnitude, but will now aid the current in the conductor. Hence, the effect of these two conductors on one another will make the current density more uniform than is the case where the two conductors adjacent to one another are carrying current in opposite directions; therefore, the resistance and the heating for a given current will be smaller. If the two return conductors are situated on the line passing through the center of the conductors just considered, the effect will be to still further concentrate the current; the distribution symmetry will be further disturbed, and the resistance of the conductor system increased.

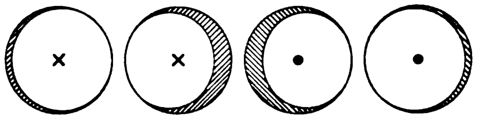

Fig. 15.

It is therefore difficult to say which of the two cases considered holds the advantage so far as increasing the resistance is concerned. The case, however, in which the phases are mixed has much the smaller reactive drop.

Conclusion

In order to help the evaluation of the various formulæ given in this article, the following table (with corrections for $q = 20$) is copied from the proceedings of the English Institution of Electrical Engineers.

If numerical values are required from the formulæ, it must be remembered that the latter are all expressed in the c.g.s. system of units; hence the following conversion multipliers must be used to obtain results in practical units:

Resistances must be multiplied by 10^{-9} to convert to ohms.
Currents must be multiplied by 10 to convert to amperes.

E.M.F.'s must be multiplied by 10^{-8} to convert to volts.

Self-inductions must be multiplied by 10^{-9} to convert to henrys.
Lengths must be multiplied by 0.395 to convert to inches.
Current densities must be multiplied by 64.5 to convert to amperes per square inch.

The specific conductivity of copper in c.g.s. units is 0.000619 and the resistance 1620; other materials being in proportion to their specific resistances relative to copper.

q	ber q	bei q	ber$'q$	bei$'q$	$\frac{bei'ber-ber'bei}{ber'^2+bei'^2}$	$\frac{q}{2}\,\frac{bei'ber-ber'bei}{ber'^2+bei'^2}$
0.0	1.000	.000	.000	.000	∞	1.000
.5	.999	.0625	− .0078	.2499	4.000	1.000
1.0	.984	.2496	− .0624	.499	2.000	1.000
1.5	.921	.557	− .2100	.730	1.367	1.026
2.0	.752	.972	− .493	.917	1.080	1.080
2.5	.400	1.457	− .943	.998	.940	1.174
3.0	− .221	1.937	−1.569	.880	.878	1.318
3.5	−1.194	2.28	−2.336	.435	.853	1.492
4.0	−2.563	2.292	−3.134	− .491	.839	1.678
4.5	−4.299	1.686	−3.754	−2.052	.828	1.863
5.0	−6.230	.116	−3.844	−4.354	.817	2.04
5.5	−7.973	−2.79	−2.907	−7.373	.807	2.219
6.0	−8.858	−7.335	− .293	−10.846	.798	2.394
8.0	20.97	−35.01	38.29	−7.66	.774	3.09
10.0	138.84	56.37	51.37	135.23	.759	3.794
15.0	−2969.8	−2952.3	86.65	−4089.2	743	5.573
20.0	47583.7	115000	−48800	111600	.734	7.345

THE TUNGSTEN SERIES LAMP

By Henry Schroeder

The great success achieved by the tungsten series lamp in street lighting is of prime importance to the central station; for now, instead of the yellow, dingy, inefficient and short lived carbon lamp, there is available in the tungsten a source of almost pure white light, which maintains its original brilliancy and candle-power until burnt out, representing on an average a life of two thousand hours.

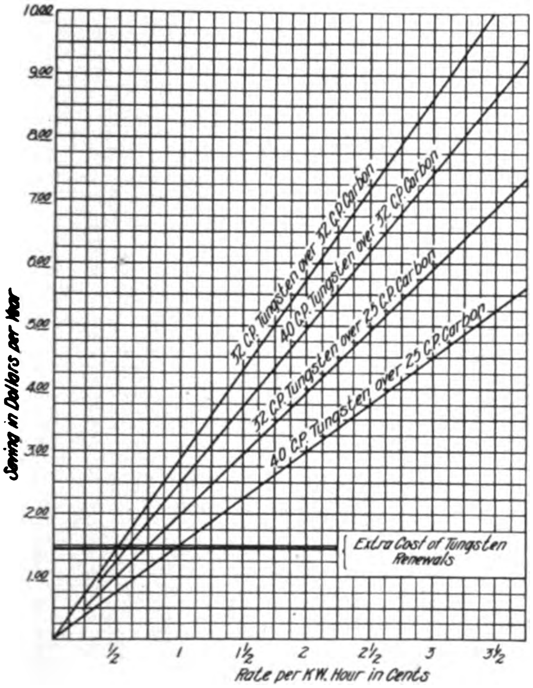

Fig. 1. Annual Saving Tungsten Series Lamps vs. Carbon Series Lamps

The increase in the use of tungsten lamps has been remarkable during the past year. On February 1, 1908, the sales of tungsten series lamps amounted to 8½ per cent. of the series lamp business, while on February 1st of this year, the orders for this lamp had increased to such an extent that they represented over 85 per cent.; the manufacture of carbon and gem series lamps having been discontinued altogether.

Chief among the advantages of the tungsten lamp is its high efficiency, which results in benefit to the central station in two ways: First, only one third of the energy required by the carbon lamp is necessary to give the same candle power; and second, due to this reduction in necessary power, the capacity of the station apparatus, in number of lamps, is trebled.

As an illustration of the benefit to be derived from the substitution of tungsten for carbon lamps, the case of a central station company in New York State may be cited. This company had 1800-25 c.p. carbon lamps attached to its circuits; an order for 700 additional lamps was received, but as the constant-current transformers were fully loaded, this extra business could not be handled without an increase in transformer capacity. By substituting tungsten lamps of 32 c.p. for the 25 candle-power carbons, and rearranging the circuits, the company was enabled to carry the load of 2500 lamps on the original apparatus, with one transformer cut out of service.

Fig. 1 shows the saving in dollars for tungsten over carbon series lamps, for a 4000-hour yearly service at various rates per kilowatt hour. The average life of the carbon lamp is here taken to be 1000 hours (high) and that of the tungsten, 1350 hours (low). The horizontal line shows the extra cost of tungsten renewals over carbon renewals, and where this line crosses the others, gives the rate per kilowatt hour at which the saving in energy just offsets the extra cost for renewals. At any rate above this there is a saving in using tungsten lamps. The cost of lamps is based on the price charged central stations whose total requirements for all types of incandescent lamps average one thousand per year; for larger stations, the cost for renewals will be less than the value shown on the curve.

In competition with the gas mantle for street lighting, the tungsten series lamp should eventually reign supreme. A certain gas and electric company in Connecticut is replacing its gas-mantle street lamps with tungstens, as the latter were found to be more profitable. One great disadvantage of the gas mantle is that it falls off seriously in candle-power after a comparatively short life (33 per cent. in 150 hours), and consequently, if the lamp is not frequently trimmed—which is an expensive operation—very poor service will result.

The cost of trimming, repairs, and incidental labor amounts to from $11.00 to $15.00. The consumption of gas averages about 14000 cubic feet per year of 4000 hours service. Assuming the price of gas to be $1.00 a thousand, and the cost of maintenance $11.00, the total cost of the lamp per year will be $25.00. Of course, the price of $1.00 a thousand for gas includes the interest on the investment and the depreciation of the street fixture.

At the same income per lamp per year, the 40 and 60 candle-power tungstens will obtain, respectively, about 10 and 7 cents per kilowatt hour for power supplied, after deducting cost of renewals.

Fig. 2 shows the rate per kilowatt hour obtainable for 40 and 60 candle-power tungsten series lamps, to meet the cost of the Welsbach mantle at various rates for gas for 4000 hours yearly service. The mantle takes 3 1/2 cu. ft. per hour (14000 cu. ft. per year), and the maintenance is 3 cents per night ($10.95 a year). The cost of tungsten renewals has been deducted.

The tungsten series lamp is made in practically all of the standard candle-power and ampere ranges, and in the event of its adoption, no change in present apparatus will be necessary. An especially good feature of the tungsten is that the high ampere lamps are every bit as good as those of low amperage; which fact eliminates the necessity of the central station maintaining two circuits, one for arcs and the other for incandescents.

Remarkable results have been obtained from the four ampere lamp on magnetite arc circuits, one central station in Pennsylvania having discarded carbon lamps and substituted tungstens on account of the trouble experienced with the former. The tungsten lamps have given entire satisfaction.

The long life of the tungsten has enabled central stations using many lamps to cut down considerably the cost of labor involved in trimming. In one specific case only four men are required to look after the lamps, where formerly, with carbon lamps, six were necessary. Due to the minimum amount of attention required by the tungsten series lamp, several companies in Massachusetts are substituting clusters of tungstens for series arc lamps. Not only is the maintenance cost of tungstens smaller for installations in outlying districts, but the power consumed is actually less, only about 350 watts being required to give the same results as obtained from the series arc.

In replacing carbon with tungsten lamps, the general practice has been to give a slightly higher candle-power, maintaining the yearly cost the same; in this way, the towns have profited by the change, as well as the power companies.

This practice should be continued, for street lighting has been woefully inefficient in the past. There should also be a tremendous increase in this class of business, as the towns are now getting so much better service for their money.

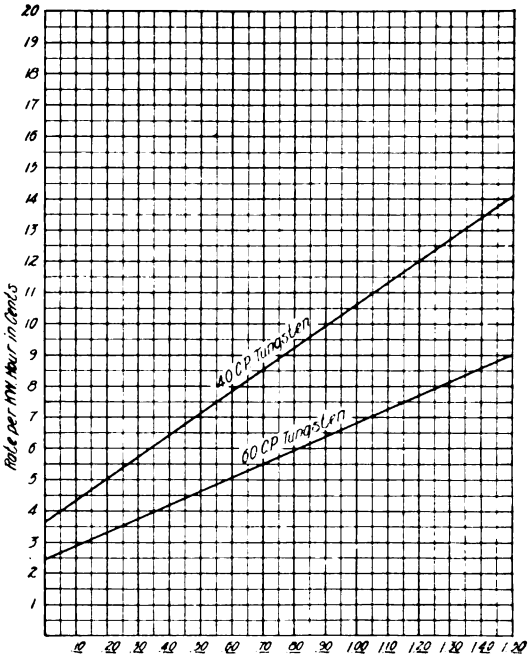

Fig. 2. Comparative Rates Tungsten Series Lamps vs. Welsbach Mantle Gas Lamps

The following are a few of the larger installations of tungsten series lamps:—

New York Edison Co., New York City, 2200, 40 and 60 c.p., 5.5 and 6.6 amp.
Richmond Lighting & Railway Co., Staten Island, N. Y., 4300, 40 c.p., 1.75 amp.
Edison Elec. Ill'g Co., Boston, Mass., 4000, 40 and 60 c.p., 6.6 amp.
Public Service Corporation, Newark, N. J., 4000, 32 and 40 c.p., 5.5 and 7.5 amp.
Grand Rapids Edison Co., Grand Rapids, Mich., 700, 60 c.p., 5.5 and 6.6 amp.
Edison Elec. Ill'g Co., Detroit, Mich , 600, 40 c.p., 1.75 amp.
Gloucester Elec. Co., Gloucester, Mass., 1000, 32 and 40 c.p., 6 amp.
Hartford Electric Light Co., Hartford, Conn., 1300, 40 and 60 c.p., 5.5 and 6.6 amp.
Suburban Gas & Elec. Co., Revere, Mass., 1200, 32 and 40 c.p., 5.5 and 6.6 amp.,
City of Seattle, Washington, 5000, 40 c.p., 6.6 amp.
New York & Queens Electric Light & Power Co., Long Island City, N. Y., 1700, 40 and 60 c.p., 6.6 amp.

DIRECT CURRENT PORTABLE DRILL

By R. E. Barker

Small Motor Department, General Electric Co.

Manual labor in construction work usually forms one of the largest fixed expenses thereof, and any device which will reduce the amount of such labor, or which will increase the value of the individual laborer's output, will result in a proportional saving of time and reduction in expense. A machine which will effect these desirable results will of necessity be adopted by progressive manufacturers, contractors, and artisans.

Drilling is an operation very widely performed in all trades and construction work; therefore, a description of a new direct current portable drill now being marketed by the General Electric Company will be of interest to many readers. This drill has been specifically designed to meet the demand for a tool that would be durable, compact, light in weight, and reliable in operation. Such a tool must be strong and well built, for in the majority of cases it falls into the hands of men accustomed to doing heavy mechanical work; consequently, any frail device would have but a short life.

The new motor illustrated herewith embodies the results of the two-fold experience gained from the manufacture of motors of this class for a period of several years, and the comparative tests of several similar machines now offered in the open market. This construction is a distinct advance in design over all previous models, and it is desired to call particular attention to the following mechanical features:

Steel Frame

This secures light weight, as well as high permeability for the field circuit; and being turned true on the outside, presents a pleasing appearance.

End Heads

These are constructed of aluminum alloy and so shaped that maximum strength is secured with desired lightness. The screws which hold the several parts together are set in counterbored holes, so that there will be no projecting parts to catch lint or tear the hands of the user.

Switch

This device is located within the magnet frame on the right-hand side and is controlled by a knurled button which serves also as an indicator; the words "ON" and "OFF" being cast into its surface. This button is of liberal dimensions and is protected from injury by a substantial guard.

Handles

The drill is regularly equipped with a side handle (through which the two-conductor lead cable is brought out) and a combined handle and breast plate at the back of the motor; also, the head from which the chuck shaft emerges is knurled and affords further convenience in handling.

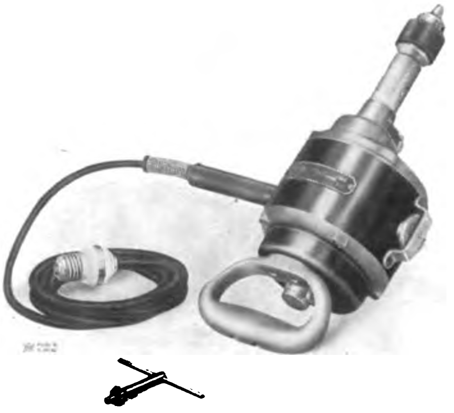

Fig. 1. Portable Drill fitted with Spade Handle

If desired, a spade handle may be substituted for the breast plate without difficulty. This does not interfere with the use of the drill in cramped positions, such as when drilling in corners, near side walls, or in other narrow quarters.

Brushes and Commutator

These are placed at the opposite end of the motor from the chuck spindle, and are totally enclosed by a sheet metal cover held in place by the same screws which hold the breast plate or spade handle. The cover is lined with felt to make a dust tight fit and to prevent rattling; it may be easily removed to expose the brush-holder, brushes and commutator, for examination when required. The brushes are rectangular in section, are fitted with pig-tails suitably insulated, and are supported in holders which provide for adjustment of pressure on the commutator. The brush holders are exceptional in their simplicity of design and minimum number of parts. The commutator is carefully constructed and is insulated with high grade mica throughout; it is provided with a generous number of bars, so that sparking is avoided.

Oiling Devices

The motor is not provided with the usual type of oil cups, as the tool is used in many positions and self oilers would cause annoyance from unavoidable leakage. Instead, small chambers holding a small quantity of oil are provided. These should be filled frequently. The oil holes for the main bearings (armature shaft) are fitted with spring ball covers as an extra precaution.

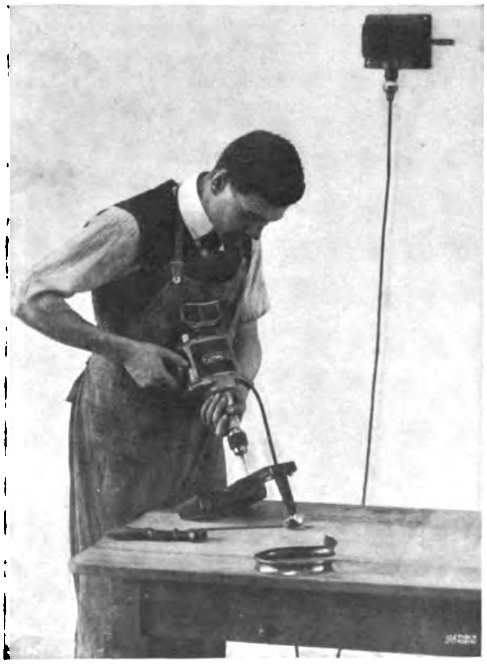

Fig. 2. Portable Drill as used with Breast Plate. Circuit Breaker on Wall

Chuck

A well-known form of adjustable chuck is regularly furnished on the drill, which will firmly hold all sizes of drills up to $\frac{21}{64}$ in. diameter. A tightening key, with pinion end to engage with a rack cut on the chuck collar, provides an easy means of securely clamping the drill, without undue effort on the part of the operator.

Leads

As mentioned under paragraph entitled "Handles," the leads consist of a two-conductor cable ten feet long, having a re-inforced insulation covered with a black linen braid. The cable is brought out through the side handle and is protected from damage by kinks or sharp bends by a supporting spring, clearly shown in the photograph. The free end of the cable is fitted with a standard attaching plug for use in Edison screw sockets or receptacles. Extension leads, of course, can also be used.

Windings

After considerable experience with portable drills, the compound winding has been adopted as the standard, as it gives speed regulation which cannot be obtained by either the series or the shunt winding. It affords most of the range of operation of a two-speed drill, without the presence of a mechanical speed changing device, the use of which reduces the efficiency and increases the weight of the outfit.

Finish

The steel frame and cover over commutator end are finished in black japan, the end heads and breast plate being satin finished. The switch and other small parts are finished in nickel plate.

The operation of the drill is approximately that represented by the curves (Fig. 3), which show the power required when operating twist drills of the size indicated. The rate of drilling is also given, but it must be remembered that this rate and the amount of power required depend upon the character of the work, the material being worked, and the condition of the drill point.

The speed of the drill chuck, when running free, is approximately 1250 r.p.m., with a wattage of about 62. The speed under load, when operating $\frac{21}{64}$ in. drill, is about 840 r.p.m. The armature speeds are 2.5 times greater, this being the ratio of the gearing employed. The efficiency of this drill is about 50 per cent. throughout the greater part of its working range. The motor has sufficient power to operate a $\frac{21}{64}$ in. drill in machine steel, cast-iron or brass. It will also operate satisfactorily a ½ in. bit in hard wood.

Accessories

It has been suggested by certain large users of portable drills that a simple form of circuit breaker be supplied in place of fuses. There appears to be a field for such an arrangement, where the portable drill is placed in the hands of careless laborers or those who do not understand how to operate it properly. The General Electric Company is therefore prepared to offer the device shown in Fig. 2.

The contrivance is an adaptation of certain parts of the new tablet board circuit breaker, mounted on a slate base and enclosed in a sheet steel case which is enameled inside and japanned outside. The front of this case is closed by a hinged cover fitted with a window which permits a good view of the breaker at all times. The main leads enter through bushings at the side and a receptacle is fitted to receive the attaching plug on the drill cable.

Cat. No.	Type	Class	Form	Winding	Volts
59098	DD	104	B	Compound	115
59099	DD	104	B	Compound	230

This circuit breaker is required to be mounted with the receptacle at the bottom, as shown. The breaker may be furnished either single pole or double pole, and it should be noted that it incorporates the "no switch in series" feature, which is one of the strong points of the standard line of General Electric double pole circuit breakers. This feature prevents the operator closing the breaker or holding it closed on an overload. The breaker is closed in two operations: first, by throwing the handle to the left, which motion inserts the switch blades between the center and left hand contacts; and second, by throwing the handle to the right, inserting the trip coils in circuit between the center and right hand contacts that are connected to the live side of the line. This apparatus is very compact and reliable, and is well suited for the purpose for which it is recommended.

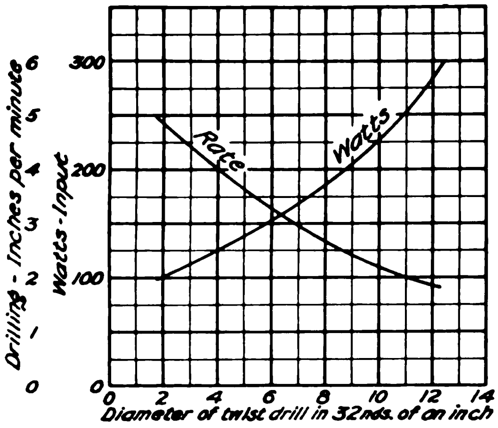

Fig. 3. Curves showing Performance of Portable Drill

The following are the salient features of the Type DD, Class 104, Form B, compound wound portable drill, which should be kept in mind:

The drill is portable, compact, durable, light in weight, safe and reliable in operation. It is easy to handle and economical in service, saves time, results in work being more rapidly accomplished, and affords an actual saving in money.

It has been adopted in large manufacturing establishments, erecting works, boiler and locomotive works, machine and repair shops, and automobile garages.

Portable drills are furnished for direct current circuits only. They are distinguished by the above catalogue numbers and ratings.

The clean cut design, careful construction and manufacture, and attractive appearance of these motors clearly marks their superiority from all points of view.

Much of the advancement achieved in manufacturing industries has been due to the adoption of machines which have permitted the substitution of power for hand labor, and wherever such drilling must be done, the adoption of the tool herein described will certainly result in a saving of both time and money. The average machine will pay for itself two or three times over, after being in service but a short time.

It has been said of the drill that it is an "incentive to the workman, a satisfaction to the foreman, and a money maker for the contractor."

IRON AND STEEL—FURNACE PRODUCTS

By J. M. Darke

The following article has been written by special request, and with the intention of making it so elementary and plain that either "he who runs may read," or he who has forgotten may refresh his memory.

As we learned in the long ago, all substances are composed of one or more well-known chemical elements; these elements, 80 in number, being so called because of the impossibility of subdividing them by any means known at present.

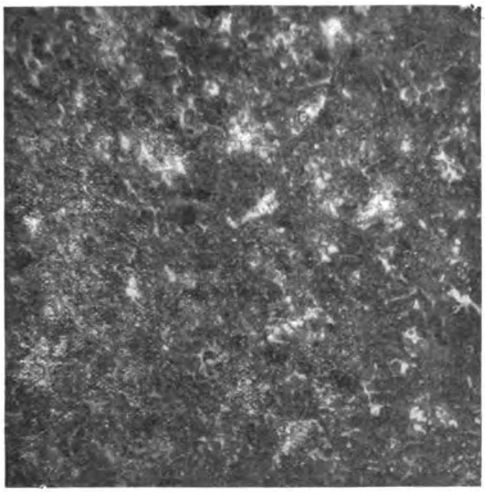

Fig. 1. Fine Grained Cast Iron. Black Spots represent Graphite; White Areas, Ferrite; Dark Areas, Pearlite. Magnified to 121 diameters

These chemical elements are grouped into classes or families in accordance with some common property; on one side the metallic elements or base formers, and on the other the non-metallic or acid formers; a few being so near the dividing line as to possess at times metallic and at other times non-metallic properties.

Among the metallic elements, we have iron, copper, nickel, lead, zinc, sodium, potassium, etc.; and among the non-metallic elements, carbon, silicon, phosphorus, sulphur, chlorine, oxygen, hydrogen, etc. Aluminum and manganese represent elements which may be either metallic or non-metallic in their properties, that is, they can form either bases or acids.

The metallic elements are not thus grouped together on account of their metallic properties, in the ordinary acceptation of the term, but because of their common property of forming salts with acids. The elements in which we are particularly interested in this paper are: iron, carbon, manganese, silicon, phosphorus and sulphur.

Iron Ore

Iron exists in the earth in several different combinations. It is never found in a free state, except possibly in meteors, but is usually combined with oxygen and earthy matter. The principal natural compounds of iron, called ores, are hematite ($Fe_2 O_3$), magnetite ($Fe_3 O_4$), and siderite ($Fe CO_3$). These exist in varying degrees of purity, usually containing water, as moisture or in chemical combination. The purest hematite contains 70 per cent. iron and 30 per cent. oxygen. Magnetite when pure contains 72.4 per cent. iron, and is attracted by a magnet. Siderite is usually so poor in iron that it is but little used in this country. It is, however, a well-known ore in England, where it is called "clay ironstone."

Carbon exists in nature in a multitude of forms. All growing things contain it, and it is a constituent of all organic substances. It is used in metallurgy mostly in the forms of coke and coal.

Carbon exists in solid iron in three conditions; namely: (1) Carbon in chemical combination with the iron; (2) free crystalline carbon, called graphite, mechanically mixed with the iron; (3) free non-crystalline carbon, called amorphous or graphitic tempering carbon.

In liquid iron, all the carbon is probably in solution.

Reduction of Ore

Almost everyone is familiar with the appearance of iron ore, and certainly there is not much resemblance between it and the various forms of metallic iron. In order to get iron ore (oxide of iron) into metallic iron, it must be treated with some substance which will readily unite with and remove the oxygen from the ore. A substance of this kind is carbon, which is usually employed for the purpose in the form of coke. Also, iron ore, being commonly associated with earthy matter, must be treated with some substance which will unite with this earthy matter and separate it as a slag. Limestone is the substance usually employed.

As these chemical reactions will not take place at ordinary temperatures, some means of raising the temperature to the required degree must be devised. This is accomplished by a suitable furnace, called a blast furnace from the fact that a very heavy blast of air is used to blow the fire and aid in the chemical reactions. The top of such a furnace is shown on the front page of the cover.

In starting the blast furnace, it is first charged with wood; this wood is then lighted and coke is added. When a sufficiently large body of coke has been fired, the ore and limestone are charged and the blast of air turned on, the air entering the sloping part of the furnace near the bottom or bosh, through holes called tuyeres.

The final reactions effected in the furnace are the reduction of the ores to metallic, liquid iron, and the combination of the earthy matter of the ore with the limestone; the latter combination, as mentioned above, forming a liquid slag. The actual reactions are not so simple as this brief statement might imply, nor do they all take place at once; however, the final result is as stated, which is probably sufficient for our present purpose.

As the iron is reduced and melts, it trickles down, with the liquid slag, through the hot coke to the bottom or hearth of the furnace, where it is allowed to remain until a quantity sufficient for a pour or cast has accumulated.

The furnace is then tapped by opening a hole in the hearth of the furnace, this opening permitting the liquid iron to run off through a suitable runner or trough to the moulds. The moulds, which are made of sand in the floor of the furnace room, consist of one large central runner with a number of smaller runners branching off from each side, these smaller runners in turn leading into single moulds. The iron which reaches the single moulds is called "pig iron," and that in the runners, "sows." Furthermore, the pig iron has a "hot" end and a "cold" end, the former being the end nearer the "sow," the latter the end further away. When the metal in these moulds is nearly set laborers break the "pigs" from the "sows" with iron bars. This is an exceedingly arduous task, which only the most robust can stand. To do away with this hard labor, casting machines are coming somewhat into use.

When a blast furnace is started, the operation is called "blowing in," and from that time on the furnace is kept in continuous use until burnt out; this period covering from 6 months to several years, according to local conditions.

Pig Iron

We have now arrived at the basis of all iron products, for pig iron is the source of them all.

Because of its great chemical activity the liquid iron does not remain pure during its journey through the furnace, but absorbs about 4 per cent. of carbon from the coke, 1 to 4 per cent of silicon from the earthy matter and brick work, and some sulphur from the fuel; while the ore itself originally contained some phosphorus, sulphur and manganese.

Pig iron is classified according to the amount of impurities absorbed by it in the blast furnace or held originally as ore. Iron containing 0.10 per cent. or less of phosphorus is called Bessemer grade; that above 0.10 per cent. phosphorus, foundry grade, the latter being further divided into various grades according to the amount of silicon and sulphur contained.

Pure iron cannot combine with more than 4 per cent. of carbon, but by the addition of some elements, such as manganese and sulphur, it can be made to combine with as much as 6 per cent. On the other hand, elements such as silicon oppose this combination with carbon. Therefore, while our liquid pig iron may contain 4 per cent. of carbon in solution, it cannot hold this amount when it cools; consequently, the carbon crystallizes out as graphite and becomes only mechanically mixed with the iron. The amount of carbon that thus crystallizes out as graphite depends upon the rate of cooling and upon the proportions of other elements present which assist or oppose the combination.

Grey pig iron contains sufficient silicon to force almost all the carbon into the graphitic state, when the iron cools slowly from a liquid, and this large amount of graphite gives the fracture of the iron a grey appearance; hence the name "grey iron." This iron is of the "foundry grade" and usually carries high phosphorus. The ordinary iron castings of commerce, with which we are all familiar, are made by remelting this iron in a modified blast furnace called a cupola, and then casting into sand moulds.

But little chemical change occurs in converting pig iron into cast iron. Some silicon and manganese are lost and some sulphur is added. An ordinary sample of soft grey iron should therefore analyze about as follows:

Carbon	Graphite	3.60	per cent.
	Combined	.25	" "
Silicon		2.75	" "
Manganese		.30	" "
Phosphorus		.70	" "
Sulphur		.07	" "
Iron		92.43	" "

Grey iron is soft and easy to machine, but weak and brittle. Its tensile strength is from 18,000 to 20,000 lbs. per square inch; its elastic limit has practically the same value, and there is little or no elongation or reduction in area. It is, however, very strong under compression.

This weakness of grey cast iron is due to the large amount of impurities it contains, and especially to the presence of carbon in large flat crystals or plates which break up the continuity of its substance.

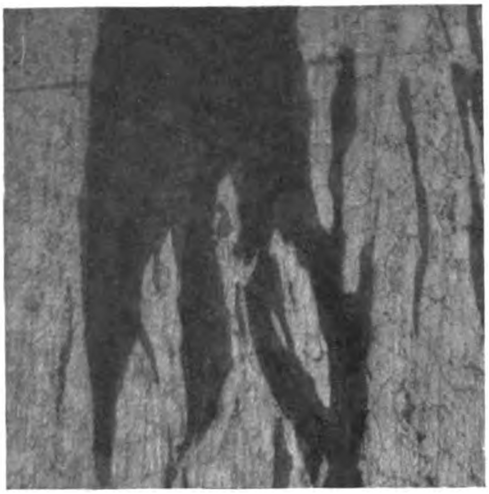

Fig. 2. Wrought Iron. Dark Streaks represent Slag. Balance Ferrite. Magnified to 121 diameters

Malleable Iron

If the pig iron does not contain enough silicon to force nearly all the carbon out as graphite when cooling, it is suitable for remelting for malleable cast iron, or as it is commonly called, "malleable iron." Pig iron chosen for this purpose usually contains about 1 per cent. of silicon and 0.20 per cent. of phosphorus. The remelting is done in an "air furnace." In this furnace, as originally designed, the heating is accomplished by hot air, generated by the combustion of coal in a part of the furnace separated from the melting chamber by a bridge wall of brick. The heat is radiated from the roof of the furnace to the stock to be melted, for which reason furnaces of this general type are called "reverberatory" furnaces. The open hearth furnace, which will be mentioned later, belongs to this class. Near the bridge wall, air pipes are introduced which blow air into the flames to make combustion more perfect.

In melting pig iron in an air furnace, some carbon and silicon are lost, and some sulphur is gained. The mixture for malleable iron is made up of low silicon pig iron such as described, malleable iron scrap, and steel scrap. The metal is poured into sand moulds, and the castings are exceedingly hard and brittle. The fracture is white, with just a sprinkling of black dots which indicate a little free carbon; most of the carbon, however, is combined with the iron.

These castings are usually packed in iron boxes with oxide of iron,—generally mill scale,—but in some places various chemicals are used in addition. The boxes are then put into a suitable furnace and subjected to a red heat for from 2 to 10 days, according to the size of the castings and to the thoroughness of the malleableization desired. Because of a growing tendency to cut down the time of heating, there has been a deterioration in the quality of malleable iron during the past few years. This heating is called "annealing," or "malleableizing." When properly done, the outside surface of the casting will consist of iron almost carbonless, the carbon having been oxidized away by the packing of iron oxide. The metal ⅛ in. below the surface will consist of iron combined with varying amounts of carbon; while in the balance of the casting, the carbon will exist free in a very finely divided state as amorphous carbon, or the "graphitic tempering carbon" mentioned when carbon was discussed.

On account of the smaller amount of total impurities present in malleable iron, and of the fact that the carbon exists in it in such a finely divided state, it is much stronger and more ductile than cast iron.

Malleable iron has a tensile strength of from 40,000 to 60,000 lbs. per square inch, and an elongation of from 2½ to 5 per cent. Its elastic limit is close in value to its tensile strength.

Good malleable iron should analyze about as follows:

Carbon	Graphitic temper carbon	3.00 per cent.
	Combined carbon	0.07 to .20 per cent.
Manganese		0.30 to .50 per cent.
Silicon		0.50 to 1.00 " "
Phosphorus		0.20 per cent
Sulphur		0.06 " "
Iron		Balance.

Grey iron and malleable iron are the only products of the "foundry iron" group of pig iron that are used for gears and pinions. There is one possible exception to this, which is the use of high phosphorus pig iron in a basic lined furnace for making basic steel. This will be referred to later

Wrought Iron

Wrought iron is made from a member of the foundry pig iron group called "forge iron" or "mill iron." Pig iron suitable for the manufacture of wrought iron contains:

Total Carbon	3.50 per cent.
Silicon	1.00 " "
Manganese	0.20 to 0.50 per cent.
Phosphorus	0.10 to 1.00 " "
Sulphur	0.05 to 0.10 " "

Wrought iron is made in a "puddling" furnace, so called because the iron is worked or puddled by hand after melting. These furnaces are usually small, holding from 500 to 2000 lbs. of metal. They are fired at one end with bituminous coal or gas, the flame passing through the furnace to a stack.

The pig iron is charged by hand, through a door in the side, and from 30 minutes to one hour is required to melt it down. When the pig iron is melted, mill scale, iron ore, or some other form of oxide of iron, is added to the metal. The object of this is to form a basic slag and liberate oxygen for the burning out of the silicon, carbon, phosphorus and sulphur. From this stage until the finish of the heat the metal is continually agitated by men using iron rods. This is called "puddling." As the carbon and silicon burn out, the metal becomes thick and pasty, due to its higher melting point and to intentional cooling by the "puddler" who operates the furnace. It is then worked into a plastic mass of metal and slag, called a "ball."

The ball is removed from the furnace with tongs and put through a "squeezer," which compresses it and incidentally squeezes out some of the slag. Of course, the whole charge is not made into one ball, but several, the number depending on the weight of the charge. From the squeezer it goes to the rolls and is there finished into puddle bars.

Puddle bars, or muck bars as they are sometimes called, are usually 3 1/2 in. wide by 3/4 in. thick, and from 12 to 18 feet long. Before this material can be made into merchantable shape, it must go through another process called "fagoting," which consists in cutting puddle bars to a required length and piling them on a plate until sufficient mass is obtained to make the desired size of billet. This pile of puddle bars is called a "pack." The packs are heated in furnaces until dripping hot, when they are removed and passed through rolls which weld the bars together and make a compact mass called a billet or bloom. This billet is then rolled into sheets or other shapes. Ordinary wrought iron of commerce should analyze about as follows:

Combined Carbon	0.20 to 0.30 per cent.
Silicon	0.10 to 0.15 " "
Phosphorus	0.10 to 0.15 " "
Sulphur	0.10 to 0.15 " "

It has a tensile strength of 45,000 to 55,000 lbs. per square inch; an elastic limit of 20,000 to 23,000 lbs.; and an elongation of 25 to 40 per cent. with a reduction in area of 40 to 50 per cent.

It is somewhat difficult for the uninitiated to distinguish wrought iron from low carbon steel. Wrought iron always contains slag (about 1 per cent.), usually no manganese, and over 0.10 per cent. phosphorus; while low carbon steel contains little or no slag, always some manganese, and phosphorus below 0.10 per cent. It is claimed, and probably to a certain extent it is true, that wrought iron pipes will not rust away as quickly as pipes made of low carbon steel. Wrought iron is not a suitable metal for gears and pinions, on account of its intermingled slag and consequent weak physical properties.

Blister Steel

Puddle bars of proper quality; *i.e.*, low in phosphorus and sulphur, obtained by carrying the puddling process farther, are converted into steel by the "cementation" process. This was probably the first method of making steel. As was noted in the description of the blast furnace, hot iron will absorb carbon from coke, and this fact is taken advantage of in the "cementation" process of steel making. Puddle bars are cut up into suitable lengths and piled with charcoal in iron boxes; these piles are then heated in suitable furnaces to a temperature of 700°C. for a week or ten days, depending on the amount of carbon it is desired to absorb, and are then allowed to cool. This cooling usually requires about a week. The resulting steel is known as "blister steel" because it is covered with small blisters caused by a gas being given off during heating. Blister steel is piled and forged in a manner similar to that described under wrought iron, and is then known as "single shear steel." This steel, when piled and forged again, is known as "double shear steel." From the very nature of the process the quality of this steel is not good, and it is doubtful if any large quantity is made in this country.

We have now shown how steel can be made from wrought iron by causing it to absorb carbon. Therefore steel, as formerly known, contained more carbon than wrought iron, the carbon being all combined with the iron and not free as in cast and malleable iron. The composition of "blister steel" would therefore be:

Combined Carbon	0.50 to 1.50 per cent.
Silicon	0.10 to 0.15 " "
Phosphorus	0.02 to 0.10 " "
Sulphur	0.02 to 0.10 " "
Iron	Balance

Blister steel has practically been superseded by the product of the crucible steel process. This process was discovered in 1740 by Huntsman, in Sheffield, England, and at that time consisted in melting "blister steel" or other highly carbureted iron in crucibles. After melting, it could be cast into ingots and rolled directly, without the troublesome work of piling or fagoting. This gave a great impetus to the steel industry, as the process was cheaper and produced more homogeneous steel. Practically all the tool steel used today is made by this method, in a more or less modified form, with a special puddle bar for the base.

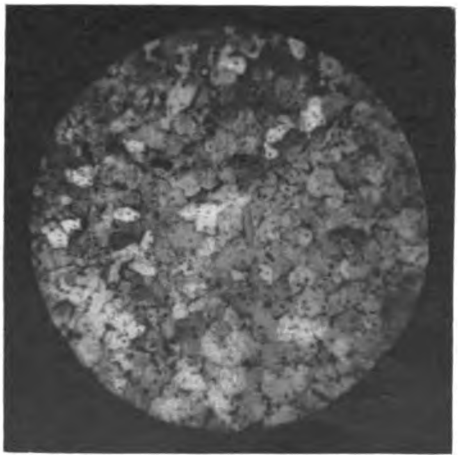

Fig. 3. Bessemer Steel. White Areas are Ferrite; Dark Spots and Connecting Lines, Pearlite. Magnified to 121 diameters

Crucible Steel

The crucibles, which are made of clay or of graphite and clay, are packed with puddle bars cut into short lengths. The crucibles are covered and placed in suitable furnaces—usually of a regenerative type fired with gas or oil. In this type of furnace the hot waste gases pass through chambers in which special fire bricks are piled in such a manner as to leave spaces for the passage of the gases. These bricks absorb a large amount of the heat contained in the waste gases; and since the direction of the air and gas is reversed every 20 minutes, the incoming gases are heated to a high temperature before they are burned in the furnace. The special bricks used are called "checker bricks," and the chambers "checker works," due possibly to the fact that in sections they look like the squares on a checker board.

Crucible steel may be good or bad, but as made for tools in this country it is very pure and has about the following composition:

Carbon (combined)	0.65 to 1.50 per cent.
Manganese	0.20 to 0.30 " "
Silicon	0.07 to 0.20 " "
Phosphorus	0.009 to 0.03 " "
Sulphur	0.009 to 0.03 " "
Iron	Balance

The different grades of crucible tool steel vary one from another in the amount of carbon contained and in the percentage of phosphorus and sulphur. With a given low phosphorus and sulphur, the several grades are due entirely to different carbon contents. For instance, a crucible tool steel suitable for chisels would contain 0.75 to 0.85 per cent. carbon, while one suitable for dies or razors would contain 1.25 to 1.40 per cent. carbon. Various alloys, such as chromium and tungsten, are now largely added to crucible tool steel. These are called alloy steels and as they are used for special purposes they have not been included in the above description. Ordinary crucible tool steel is now called "carbon crucible tool steel," to distinguish it from alloy steels.

The chemical reactions in a crucible are not easily controlled, because the amount of carbon the metal will absorb grows less each time the crucible is used. For this reason, a crucible steel manufacturer does not always obtain the grade of steel he starts out to make; therefore he makes a large number of ingots and usually has the grading done by chemical analysis after the steel is made.

By the use of clay lined crucibles and special carbon mixtures, the process can be more accurately controlled, but its general uncontrollability should be remembered when contrasting this method with the more exact open hearth and Bessemer processes, which will be next discussed. Carbon crucible steel is seldom used for railway motor gears and pinions on account of its high cost.

Bessemer Steel

The Bessemer process of steel making was discovered by Sir Henry Bessemer in 1856.

In this process, melted pig iron is taken from the blast furnace and treated in a brick lined, cylindrical steel vessel, called a "converter."

The converter has a constricted opening at the top, which is usually extended for a short distance at an angle of 20° with the long axis to prevent loss of metal by blowing out. The converter is supported near the center of gravity on two trunnions, through one of which the blast of air enters and from which it is conducted to the wind box in the bottom. The other trunnion is connected by means of a pinion to a hydraulic piston which serves to rotate the vessel through 270 degrees.

The bottom of the vessel is pierced with about 260 1/2 to 3/4 in. holes which are connected with the wind box and through which the blast enters.

To operate the converter, it is turned down on its side and from 10 to 15 tons of liquid pig iron poured in. The blast is then turned on and the converter brought to its upright position. The strong blast of air entering through the holes in the bottom serves to oxidize or burn out the impurities in the pig iron and thus convert it into nearly pure iron. The whole operation of blowing occupies only from 15 to 20 minutes, and the heat generated by the rapid oxidation of the carbon, manganese, and silicon of the pig iron is intense. As soon as the flame "drops," showing that the carbon has been practically all burned out, the vessel is turned down, the air cut off, and a certain amount of liquid ferro-manganese or spiegeleisen added, which recarburizes the iron to the desired extent.

The process of recarburizing is fairly accurate, as practically all the carbon is first burned out of the metal and then a definite amount added in a form in which it will be readily absorbed. After the reaction caused by adding the recarburizer is over, the metal is poured into a ladle and thence poured or "teemed" into iron moulds called ingot moulds. The resulting casting is an ingot, and is used entirely for rolling or forging purposes.

The products of the Bessemer converter are principally rails, wire and sheets. Practically no steel castings, as the term is commonly understood, are made by the regular Bessemer process. However, a modified Bessemer process, called the Tropenas, is used for making steel castings.

The nomenclature of iron products was fairly exact until the advent of the Bessemer converter. Large quantities of metal called steel, but having about the same composition as wrought iron, minus the slag, are now made in a Bessemer converter. A better name for this class of metal would be "ingot iron", and a number of metallurgists struggled valiantly to have this term adopted, but without success. Therefore, everything that comes from a Bessemer converter is called steel.

Bessemer steel is not so good as open hearth steel since it contains more oxygen, nitrogen and hydrogen; it is not as reliable, its strength is not as great, and bars made from it are apt to be seamy. On this account and because of the comparatively small amount of low phosphorus ores available, the Bessemer process has been steadily losing prestige until at the present time it is a question whether it can hold its own with the basic open hearth. The process is, however, particularly adapted to low carbon steels. Bessemer steel is not used for the manufacture of the highest grade of gears and pinions.

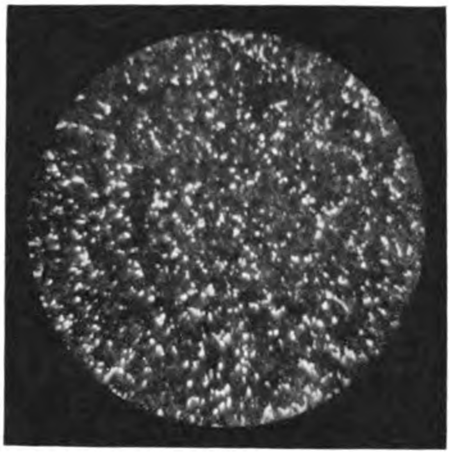

Fig. 4. Crucible Tool Steel. Light Areas are Cementite; Dark Areas, Pearlite. Magnified to 121 diameters

Open Hearth Furnaces

The open hearth process of steel making consists in melting a mixed charge of pig iron, scrap steel, and iron ore, on a sand bottom in a reverberatory, regenerative furnace. The nature of the lining of the bottom and sides decides whether the process is acid open hearth or basic open hearth. If lined with silica (which is chemically acid) the process is acid open hearth, while if lined with magnesite or dolomite (which are chemically basic) the process is basic open hearth. The furnace remains the same, whether the lining is acid or basic. The melting is accomplished by producer gas, natural gas, or fuel oil.

Basic Open Hearth Steel

In the basic open hearth process, pig iron of the foundry grade is chosen because of its cheapness. It may be high in phosphorus and sulphur, but should not contain more than 1 per cent. of silicon, because the silicon when oxidized is acid in character and requires an extra amount of lime to neutralize it. Along with the pig iron are charged cast and malleable iron scrap, cheap steel scrap, iron ore and limestone.

After the metal is melted the heating is continued until the silicon and manganese are eliminated, and until the carbon, phosphorus and sulphur have been reduced to the desired amount. The limestone added forms a basic slag, which in turn serves to eliminate the phosphorus and some of the sulphur. The carbon, silicon and manganese are removed by combining with the oxygen of the air and with that of the iron ore used. Test pieces are dipped from the furnace and analyzed for carbon and phosphorus by quick methods. This gives a means of controlling, with considerable accuracy, the composition of the steel.

A basic lining is employed in this process on account of the basic nature of the slag used to remove the phosphorus. If an acid lining were used, the basic slag would combine with it and destroy it.

Basic open hearth steel is made in all possible compositions of steel. The metal is cast into ingots for rolling in a manner similar to that employed in the Bessemer process. Basic open hearth has been used to some extent, but not very successfully, for steel castings, such as motor frames, gears, etc. The rolled and forged metal of proper composition is suitable for the manufacture of gear rims and pinions.

Acid Open Hearth Steel

The acid open hearth is very similar to the basic, with the exception that a silica lining is used. The slag is acid in character, and the pig iron and scrap steel charged must be very carefully selected, as there is no elimination of phosphorus and sulphur in this process. Steel made by the acid open hearth is believed by many to be better than basic steel; this is probably due to the fact that basic steel contains more oxygen than acid steel, and consequently, for steel casting work, will not give as sound castings as acid steel. It is a fact, however, that the basic open hearth has superseded the acid open hearth for practically everything except steel casting work.

Having now briefly considered the principal processes for the production of iron and steel, the selection of these materials for the manufacture of railway motor gears and pinions will be discussed in a future paper.

BOOK REVIEWS

ELECTRICAL ILLUMINATING ENGINEER

By Wm. Edward Barrows, Jr.

McGraw Publishing Company 216 Pages Price $2.00, net

In "Electrical Illuminating Engineering" the author has prepared a book which is concise and at the same time fairly comprehensive.

The introductory chapter, under the heading of "Light and Color," treats briefly of color and other values pertaining to light and illuminants. Some interesting tables are introduced, although the authority for much of the collected data is not given. This is followed by several chapters on the measurement of light, the defining of units, and the describing of photometers and methods. In one or two respects the information does not altogether represent the usual American practice.

The body of the book is made up of matter descriptive of the different types of lamps and accessories. In describing incandescent lamps the line of distinction has not been clearly drawn between lamps in commercial use and those which are merely in an experimental stage.

The concluding chapter of the book treats of illumination and calculation and is given up largely to the calculation of foot candle illumination from photometric curves.

As a whole, the book contains much interesting information and may profitably be used by a discriminating engineer.

The art of Illuminating Engineering is progressing and changing so rapidly that it is a difficult matter to crystallize the state of the art in a representative treatise.

ELECTROMETALLURGY

By John B. C. Kershaw

D. Van Nostrand Co. 303 Pages Price $2.00, net

This book gives an account of the industrial developments of electrometallurgy. There is no attempt at any theoretical treatment of the processes described, and the whole is written with an absence, as far as possible, of technical terms; so that the subject matter is readable to those having but the slightest understanding of chemistry or electricity. The electro smelting and refining of aluminum, copper, iron, lead, nickel, tin and zinc are treated in separate chapters. The preparation of sodium, and the refining of bullion and gold are also treated individually. Other subjects, which are given independent chapters, are the preparation of calcium carbide and acetylene, carborundum, ferro alloys, glass and quartz-glass and graphite. A chapter is also devoted to miscellaneous subjects, including calcium, carbon bi-sulphide, carbon tetrachloride, diamantine, magnesium, phosphorus and silicon. The various subjects are, in general, all treated in the same way: historical introduction, production and costs, description of processes and plants illustrating these.

The author of this book, while not giving new information to those in touch with this development of industrial science, has succeeded in giving an intelligent, interesting and up-to-date account of things accomplished in this rapidly developing industry.

GENERAL ELECTRIC REVIEW

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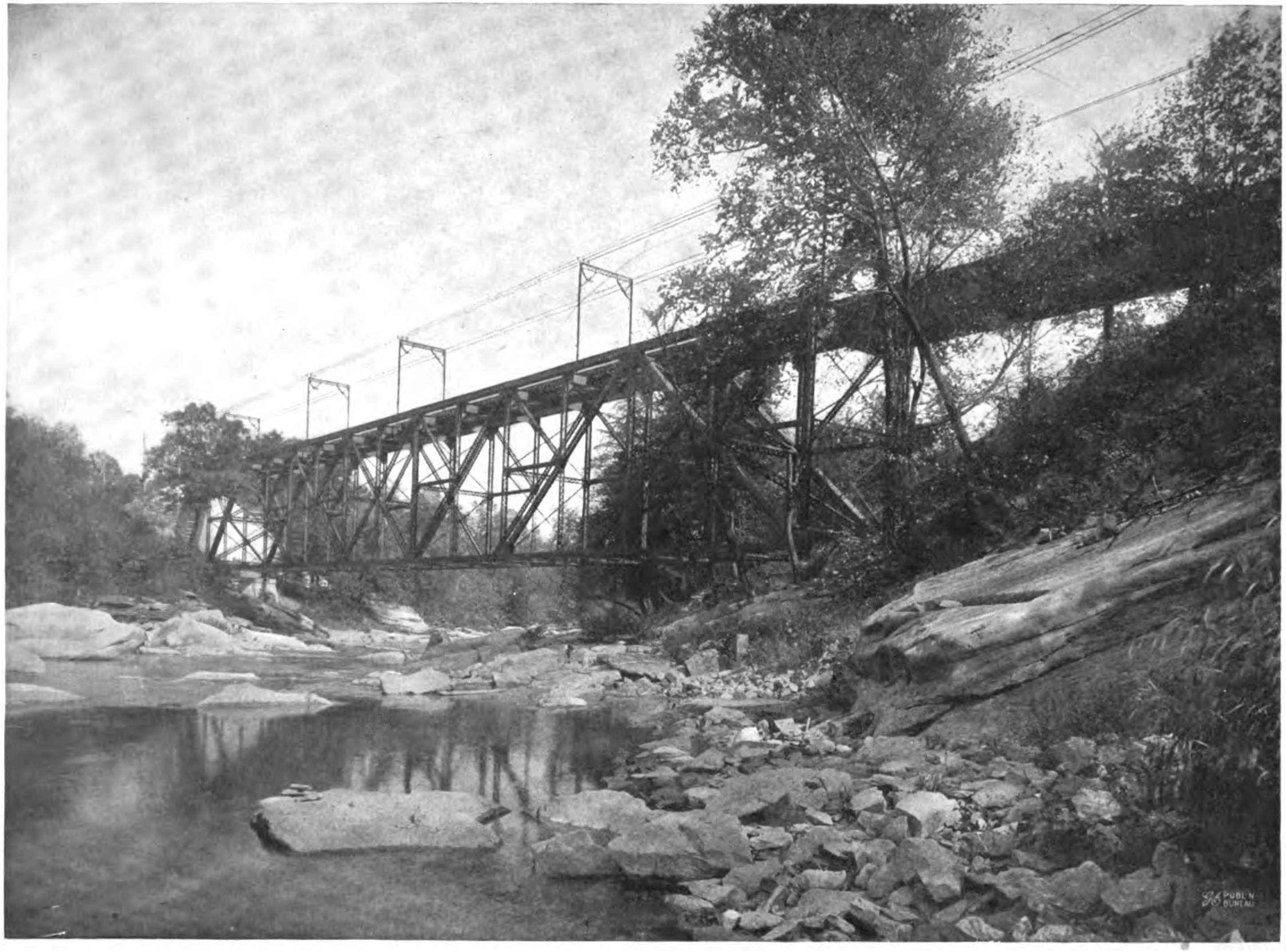

Buhl Bridge, Pittsburg, Harmony, Butler and New Castle Railway
1200 Volt Direct Current Operation
(See page 253)

GENERAL ELECTRIC REVIEW

VOLTAGE REGULATORS

The accurate regulation of voltage both for alternating and direct current systems, is a matter of utmost importance; and the economy resulting therefrom is unquestionable—a fact well known to all station masters who endeavor to operate their plants upon an economical basis. Especially is this true in all plants where the load is liable to violent fluctuations, as for example, in the case of combined railway and lighting systems.

In view of the fact that the importance of close regulation of voltage has long been recognized and that voltage regulators have come into almost universal application, it is somewhat strange that no more has been written upon the subject The article on Voltage Regulators, appearing on page 267 of the present issue, is the first of a series in which the various applications of these devices and the methods of their employment will be described.

The fundamental principle upon which these regulators operate is essentially different from that of other types, which depend upon altering the strength of the field current by varying the resistance of the field rheostat; a method which is apt to lead to hunting, on account of the inability of the switching mechanism—through the length of travel and inertia of parts—to respond with sufficient rapidity to the fluctuations of the voltage.

In the case of the TA and TD regulators, however, the varying of the field strength is accomplished by rapidly opening and closing a shunt circuit across the field rheostat of the source of excitation; this usually being the generator itself, in the case of a d.c. machine, and the exciter in the case of an a.c. machine.

The arm carrying the contacts is very light, and the distance through which it plays is only about $\frac{1}{16}$ of an inch; it is obvious, therefore, that the factors that make for hunting in the other types of regulators have been eliminated in these devices.

In their various forms, these regulators may be classified according to their uses as follows:

Direct Current

I. Voltage regulator (a) for maintaining constant voltage at the terminals of a direct current generator, or (b) for regulating the voltage at the generator so as to maintain a constant voltage at a distant point.

II. Constant current regulator for motor-generator fly wheel sets for hoisting, etc.

III. Constant current regulator for storage battery booster, to maintain a constant load on the source of supply.

Alternating Current

IV. Voltage regulator (a) for maintaining a constant voltage at the terminals of an alternating current generator, or (b) for regulating the voltage at the generator so as to maintain a constant voltage at some distant point (also used as I above when the direct current generator has a separate exciter).

V. Constant current regulator for alternating current generator. Used with synchronous motor direct current generator set and storage battery.

VI. Constant voltage regulator. Used in connection with a synchronous motor at the receiving end of the line, for maintaining constant voltage by varying the power factor.

VII. Constant power factor regulator, for holding a constant power factor on a synchronous motor.

1200 VOLT DIRECT CURRENT RAILWAY OPERATION

The rapidly increasing interest which is being shown in the 1200 volt direct current railway system is evidence of the fact that it has substantial advantages over both the 600 volt d.c. system and the single-phase system for a certain class of interurban work.

It is not generally appreciated that in Europe, which is generally considered the stronghold of the single-phase system, there are almost as many high voltage direct current systems in operation as there are single-phase systems. To be exact, there are now nine different railways operating with direct current at voltages ranging from 900 to 2400, while there are several others operating at 750 volts.

The *raison d'être* of the single-phase system is the low first cost of the distributing system (sub-station and working conductors); but this is obtained at the expense of a considerable complication and elaboration of the motor car equipments. Oil switches are necessary to control the circuits, a heavy transformer to supply the proper low potential, and the motors must be provided with additional windings to make commutation possible. It is therefore evident that the equipments must cost more than d.c. equipments, and as a natural corollary, it will cost more to maintain them in proper working condition. This increased cost of up-keep would naturally be at least in proportion to the increased first cost, and in view of the pulsating torque and commutation difficulties in the a.c. motor, it can easily be imagined that it would be in still greater proportion.

The article on another page by Mr. Hill describes characteristics of the 1200 volt system, and gives an interesting comparison between that and the single-phase system.

A careful consideration of the characteristics of the two systems shows that a 1200 volt road can be built with a much less costly distributing system than can the standard 600 volt system, and that the cost of up-keep of the equipments will not be much greater than for similar 600 volt equipments.

Thus the 1200 volt equipments provide us with a system closely approaching the single-phase system in first cost and the 600 volt system in low cost of operation and maintenance.

THERMODYNAMICS

Dr. Steinmetz completes his series of articles on Thermodynamics in this issue of the REVIEW by considering the general steam characteristics of the expansion and impulse types of turbine and their relation to turbine velocity, leading up to a discussion of the combination turbines which are now in commercial use The part that steam friction plays in the economy of the turbine is clearly brought to notice, and the effect of re-evaporation of the moisture, caused by expansion, on the distribution of the mechanical energy in the turbine stages is lucidly explained. The author comments on the equivalence of superheated steam and negative moisture, and concludes with a warning in reference to the application of the steam energy equations to turbines, for which the proper methods of calculation were given in the May REVIEW.

The Steinmetz articles form a notable series and will repay careful study by those who are anxious to acquire an insight into this difficult subject, and its applications to steam or gas movers. The method of deriving the fundamental equations from dynamical considerations is original, and the whole question has been so treated as to illumine many of the dark places of the Science.

DRAWN SHELL MOTORS

The article on Drawn Shell Motors by Mr. H. S. Baldwin describes a recently developed line of motors in which the stators and direct current fields are built up of punchings, these punchings being assembled under compression and pressed into a steel shell, which takes the place of the customary cast iron outside frame. This construction secures much smaller diameters than heretofore and permits a degree of accuracy in manufacture otherwise impossible.

These features, however, are of secondary importance to the electrical characteristics, which are particularly advantageous, the motors possessing high efficiency and power factor, together with liberal overload capacity with moderate heating.

THE SYNCHRONOUS ALTERNATING CURRENT MOTOR

PART II

BY F. B. CROCKER AND M. ARENDT

Operative Limits of Synchronous Motor

The rotation of a synchronous motor, as already explained, is absolutely dependent upon the maintenance of synchronous relation with the line voltage. Hence the driving power is exerted through a relatively easily broken link, somewhat flexible it is true, but not so strong as that of the series, shunt or induction motors, which *gradually* drop in speed and finally become stalled upon application of excessive overload; whereas the stoppage of a synchronous motor is very sudden.

This abrupt stopping of a synchronous motor is due to the very fact upon which the ability of the machine to carry variable loads depends; namely, the phase swing of the armature e.m.f. with respect to the line voltage as load comes on, thus increasing the resultant pressure and armature current. This retardation of the motor armature cannot indefinitely increase its driving power, because ultimately the phase angle between motor voltage and current approaches 90°, at which limit the power falls to zero ($E_m I \cos \phi_m = 0$) and the machine stops, if it has not already done so before the 90° limit is reached. Practically, the stopping would occur before ϕ_m is reduced to 90° because the driving power must be sufficient to overcome the core losses, windage, friction, etc., plus any external load.

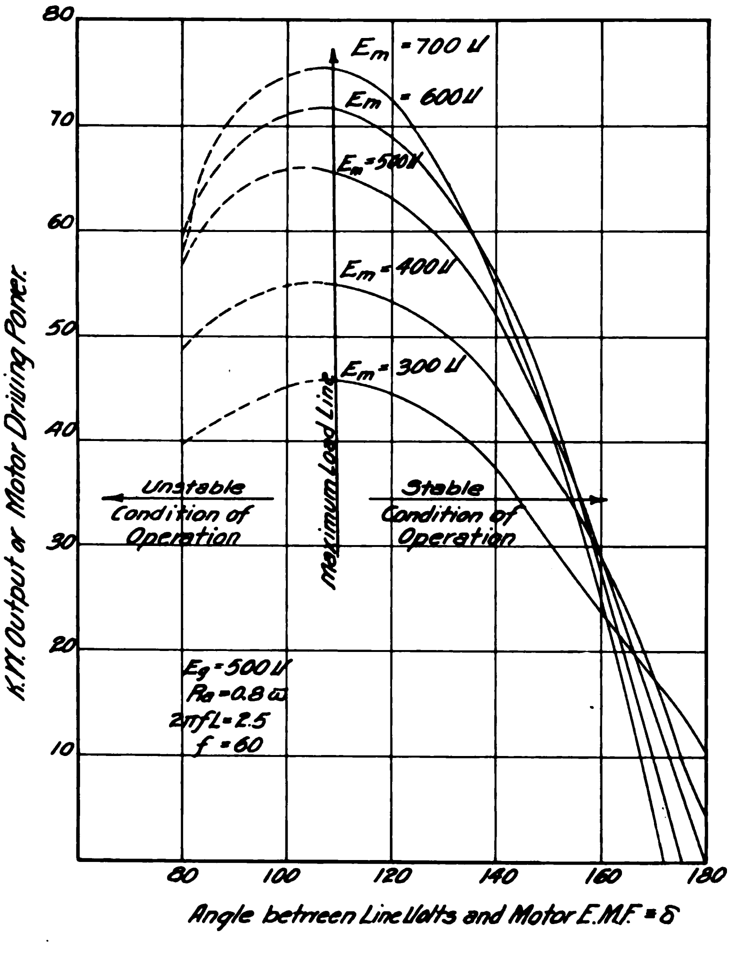

Fig. 17. Operative Range Curves of a 30 Kw. Single-Phase Synchronous Motor

Investigation of the operative range curves (Fig. 17) of the synchronous motor indicates that such machines have two conditions of operation; namely, a stable and an unstable one. The unstable condition of operation exists when the phase angle between armature and line voltages is less than a certain value, ranging between 100° and 120°, depending upon the resistance and reactance of the motor armature. Thus, if the motor should be operating on the unstable portion of the curve; that is, between zero and about 110°, any attempt to increase the load would be accompanied by retardation of the armature, which would not, however, augment the driving power of the machine; with the result that the synchronous link is broken and rotation ceases. Conversely, while operating on this unstable portion of the curve, if the motor load be decreased, acceleration of the armature results which augments the driving power of the machine, and acceleration is continued until the crest of the power curve is passed and the stable condition reached.

The stable condition of operation for synchronous motors exists when addition of load causes a retardation of the armature with increase of driving power which continues until load and driving power balance. If, however, it be attempted to overload the motor considerably, the resulting retardation of the armature causes the angle between the motor e.m.f. and line voltage to decrease so that it is less than the value corresponding to that of maximum driving effort; therefore the motor passes into the unstable condition of operation and stoppage results. If the load on the motor be decreased while the motor is operating on the stable portion of the curve, the armature is accelerated and the driving power decreased until a balance is obtained.

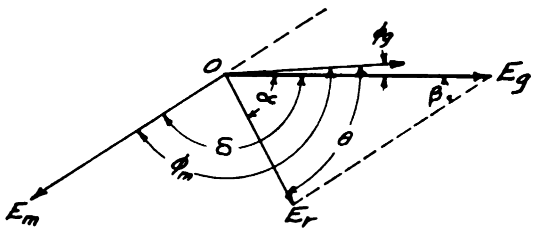

Fig. 18. General Vector Relations of Line Voltage, Current and Motor E.M.F.

The range of driving power, and thus the capacity of a given synchronous motor, depends upon its field excitation and armature constants (resistance and reactance of its winding). The driving power of such a machine is generally greater the stronger its field, within the limits attainable in practice. For different machines, other things being equal, that one having the larger impedance angle ($\tan^{-1} 2\pi f L \div R$) has the higher overload capacity or greater stability.

The approximate operative range of any synchronous motor for various conditions of excitation can be predetermined if the line voltage, armature e.m.f., resistance, inductance and frequency are known. The equations for this calculation are obtained from the ordinary diagram showing the vector or space relations between the line voltage, current and armature e.m.f. Inspection of Fig. 18 shows that the resultant voltage

$$E_r = \sqrt{E_m^2 + E_e^2 + 2\, E_m E_e \cos\delta}$$

where δ is the angular relation between motor and line voltages. From this value the armature current can be obtained by dividing the resultant voltage by the armature impedance, thus:

$$I = E_r \div Z = \frac{\sqrt{E_m^2 + E_e^2 + 2\, E_m E_e \cos\delta}}{\sqrt{R^2 + 2\pi f L^2}}$$

The driving power of the motor, or that portion of the input converted into mechanical power, is

$$W_m = E_m I \cos\phi_m$$

ϕ_m being the angle between motor voltage and line current. The value of this angle ϕ_m depends upon the phase relation between line voltage and armature e.m.f., the value of these voltages and the constants of the armature circuit or

$$\phi_m = \delta + \theta - \cos^{-1}\frac{E_e + E_m \cos\delta}{E_r}$$

$$\text{Thus } W_m = \frac{\sqrt{E_m^2 + E_e^2 + 2\, E_m E_e \cos\delta}}{Z} \times$$

$$E_m \cos\left[\delta + \theta - \cos^{-1}\frac{E_e + E_m \cos\delta}{E_r}\right]$$

where θ is the impedence angle of the motor armature. These equations will now be applied to the determination of the operative curves of the following synchronous motor and its range of operation at excitations corresponding to motor armature voltages of 300, 400, 500, 600 and 700 volts determined.

Rated Capacity	40 h.p. or 30 kw.
Speed	900 r.p m.
Poles	8
Frequency	60 periods per sec.
Line voltage	500
Armature resistance	0.8 ohms
Armature reactance at 60 p.p.s.	2.4 ohms
Stray power losses at 500 volt excitation	2.40 kw.

It is to be noted that the possible load capacity of this machine is greatest at the highest field excitation considered; but at these heavier loads the armature current is excessive, as shown in Fig. 20. When excited so that its armature produces 500 volts counter e.m.f. the motor has about 80 per cent. overload capacity before instability is reached. At greater excitations, for example at 600 volts, the crest of the power curve occurs at 140 per cent. overload. The important fact follows that with a synchronous motor liable to be subjected to widely variable loads, greater stability is obtained by adjusting its field excitation so that the armature e.m.f. is equal to or somewhat greater than the line voltage. This increase of armature voltage should not be carried too high because the current for a given load becomes too great, causing excessive heating of the machine. For example, the armature current for 30 kw. at 500 volts is 70 amperes; at 600 volts, 82 amperes; and at 700 volts, 120 amperes.

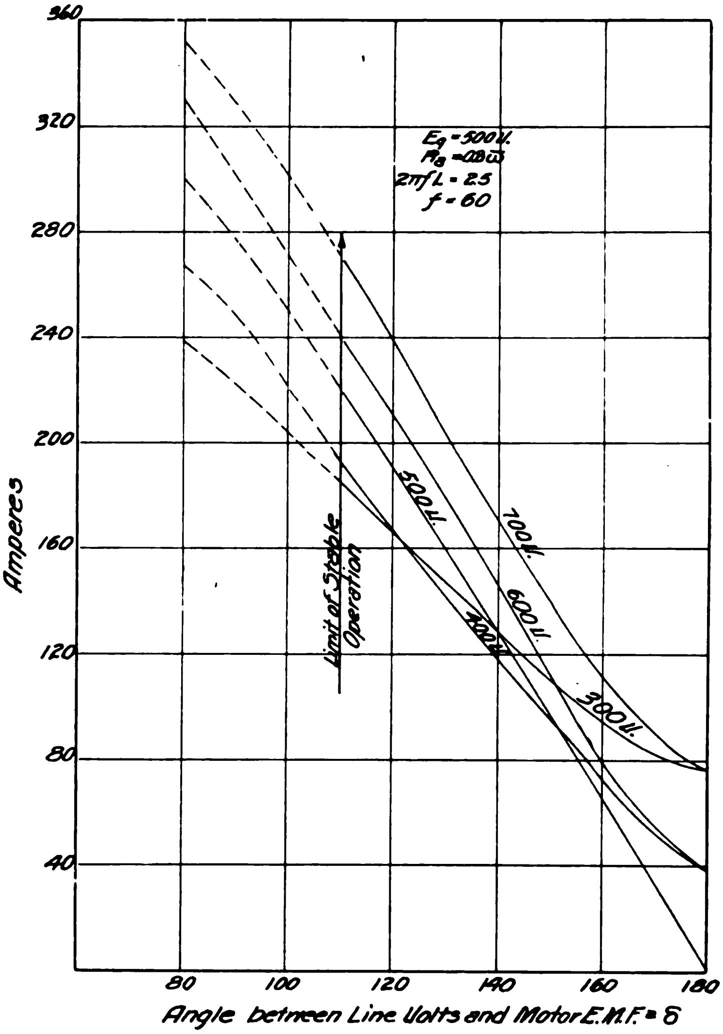

Fig. 19. "Current-Phase Swing Angle" Curves of 30 Kw. Single-Phase Synchronous Motor

Circle Diagrams of Synchronous Motor

If we consider a given line voltage and armature e.m.f. of a synchronous motor, and plot the vector positions and relative values of line voltage, armature e.m.f., resultant voltage and current through a phase swing of 180°, it is found that while naturally the locus of the motor voltage is a circle, the loci of the resultant voltage and armature current are also circles. The centers of these circles are at different points. These circle diagrams of the synchronous motor are useful and by their application the values of E_r, I, and ϕ_m can be directly determined and thus the power or operative load range curves of the motor obtained without the lengthy calculations based upon the preceding equations. One set of circle diagrams are required for each motor excitation. Their construction and application are as follows: Lay off in a horizontal direction and to scale the line OE_g(Fig. 21) representing the line voltage, then add to it, in the same direction, the line $E_gE'_m$ which corresponds with and is proportional to the motor e.m.f.; also, lay off to the left of E_g a distance proportional to and representing the motor voltage as above. Then with the point E_g as a center and E_m as a radius describe a circle. This is the locus of the resultant voltage E_r. Its maximum value is proportional to the distance from O, through E_g to E_m, while its minimum value is the distance along the same diameter from O to the point at which this diameter cuts the left hand side of the circumference; that is, the length OQ. With the point O as a center describe a circle having a radius representing and proportional to E_m. This is the locus of the motor voltage. Through the point O draw the line OK so that it makes an angle θ (the impedance angle) with the horizontal line OE_g. The location of the point K is obtained by using the point O as a center and a radius equal to OE'_m; that is, OK is equal to OE'_m. Then from the point K along the line OK towards O lay off a distance equal to E_m and with this new point P as a center and PK as a radius describe a circle. This represents the locus of the current vector and is proportional thereto, being the impedance drop, which is numerically, for any vector position, equal to the amperes multiplied by the impedance Z. The maximum current position is represented by the line OK, which is numerically equal to $OK \div Z$, being obtained when the motor voltage and line voltage are in phase (*i. e.*, 360° displacement existing between them). The minimum value of the current is the distance OL divided by the impedance and is obtained when the motor voltage is 180° from the line voltage. Three sets of circle diagrams are given. The first of these (Fig. 21) shows the loci of resultant voltage, motor voltage and current, when the motor voltage is 300 and the line voltage 500. The second circle diagram (Fig. 22) illustrates the corresponding loci when motor and line e.m.f. are each 500 volts; and the third diagram (Fig. 23) sets forth the loci when the motor voltage is 700 and the line voltage 500. Consider the first diagram, and let it be desired to obtain the resultant voltage, motor current, value of ϕ_m and driving power of motor when the angle between the motor voltage and the line voltage is 130°. The procedure is as follows: From the point O draw the line OE_m so that it makes an angle of 130° with OE_g. This represents the angular position of the motor voltage with respect to the line voltage. Then with the point E_m as a center and a radius equal to OE_g describe an arc which cuts the resultant voltage vector locus at the point E_r. OE_r represents the scale value (=375 v.) of the resultant voltage and its correct angular position. With O as a center and with the distance OE_r as a radius describe an arc intersecting the current vector locus at the point I. The line OI represents the true vectorial position of the armature current, and if its scale value be divided by the impedance, the correct value of this current is given in amperes $\left[\frac{355}{241} = 146\right]$. The angle contained between E_mOI is the angle ϕ_m and its value (166°) can be measured on the motor voltage circle. The product then of $E_mI \cos \phi_m$ gives the motor driving power, or $300 \times 146 \times -0.97 = -42.5$ kw.

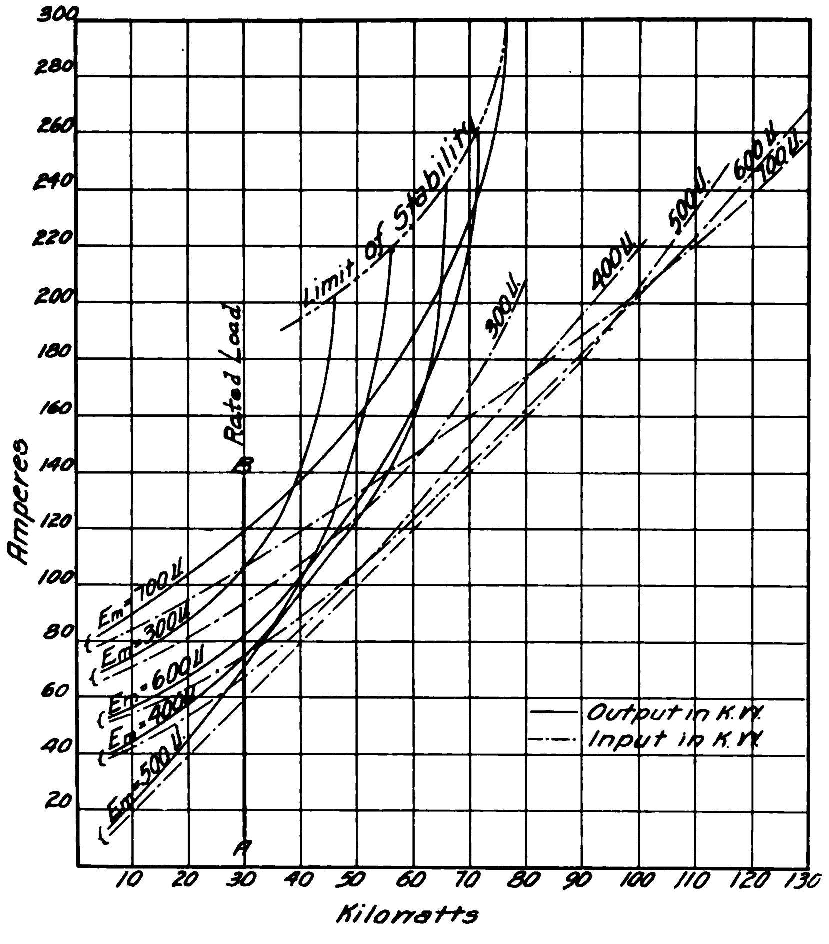

Fig 20. Current-Power Curves, 30 Kw. Synchronous Motor

Various angular positions between E_g and E_m can similarly be assumed, the current and motor driving power determined as shown, and these different values plotted as ordinates with the phase angle between E_g and E_m as abscissæ; the result being the motor "load-range curves" and "current curves" shown in Figs. 19 and 20, respectively. It can very quickly be seen by means of the operative range curves what angle between motor voltage and line voltage represents the pulling out or stopping condition, which occurs with the 20 kw. motor of the text when the angle E_mOI is a little less than 110°.

V. Curves of the Synchronous Motor

All the working characteristics of a synchronous motor can be determined from its *operative load range* curves which were derived and discussed in the preceding pages. For example, the *current-power* curves are obtained by plotting curves having corresponding current values as ordinates and kilowatts as abscissæ. Two sets of *current-power curves* exist (Fig. 20); one group showing the relation between current and output or driving power, and the other between current and armature input. The armature watts input are determined by adding the corresponding I^2R_a losses and watts output.

The characteristic *V curves* of the synchronous motor are readily determined from the *current-power* input curves, by proceeding as follows: Assume any constant input, say 30 kw., then draw the straight line AB vertically through the 30 kw. abscissa point of the current-power curve (see Fig. 20), and from the intersection of the line AB with the different input curves we can determine the various armature currents corresponding to the selected motor e.m.fs. (300, 400 volts, etc.). The relation existing between these motor e.m.fs. and current values used as abscissæ and ordinates, respectively, gives the 30 kw. *current-V curve* for the motor of the text. The complete series of these V curves given in Fig. 24 were obtained by following a like procedure for the different values of input employed.

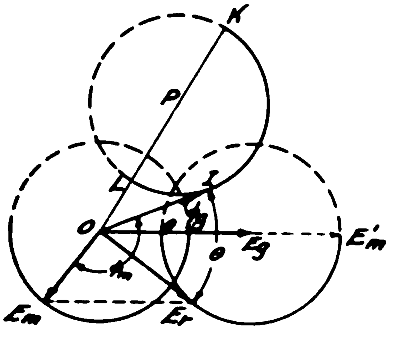

Fig. 21. Circle Diagram of Synchronous Motor; E_g = 500 Volts, E_m = 300 Volts, θ = 60°

A study of these curves indicates that at any given input, as the motor voltage is increased the armature current decreases, until a minimum value is reached, after which, upon further strengthening of the motor field the current begins to increase. The variation in the armature current for a given range of field excitation is greater at the lighter loads, and the curve obtained when the motor is running practically without load is of substantially a V shape, hence the name; while at the higher loads the curve flattens out considerably, appearing like an arc of a large circle at rated load input and beyond. These same V curves can be directly determined by calculation, employing a formula which is derived from the simple vector relations existing between line volts, motor volts and current in the case of a synchronous motor, this equation being:

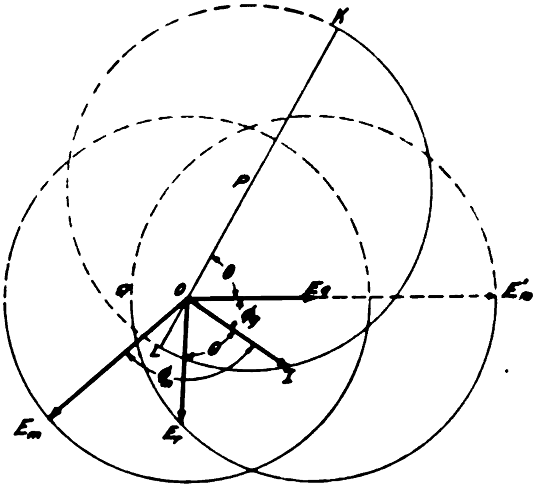

Fig. 22. Circle Diagram of Synchronous Motor; E_g = 500 Volts, E_m = 500 Volts, θ = 60°

$$E_m = \sqrt{(E_g \cos \phi_g - IR_a)^2 + (E_g \sin \phi_g - IX)^2}\,{}^*$$

but its use is rather tedious.

[*] From vector diagram, Fig. 18, it is apparent that

$$E_m^2 = E_g^2 + E_r^2 - 2E_gE_r \cos(\theta - \phi_g) \qquad \text{(A)}$$

Wherein $E_g^2 = E_g^2(\cos^2 \phi_g + \sin^2 \phi_g)$

$$E_r^2 = \overline{IZ}^2 = I^2(R^2 + X^2) \qquad \theta = \cos^{-1}\frac{R}{Z} = \sin^{-1}\frac{X}{Z}$$

$$\cos(\theta - \phi_g) = \cos\theta \cos\phi_g + \sin\theta \sin\phi_g$$

$$= \frac{R}{Z}\cos\phi_g + \frac{X}{Z}\sin\phi_g$$

Substituting the above for their equivalent terms in equation A we have

$$E_m^2 = E_g^2 \cos^2 \phi_g - 2IRE_g \cos\phi_g + I^2R^2 + E_g^2 \sin^2 \phi_g$$
$$- 2IXE_g \sin\phi_g + I^2X^2$$
$$= (E_g \cos\phi_g - IR)^2 + (E_g \sin\phi_g - IX)^2 \text{ or}$$
$$E_m = \sqrt{(E_g \cos\phi_g - IR)^2 + (E_g \sin\phi_g - IX)^2} \qquad \text{(B)}$$

which equation expresses the value of the motor e.m.f. in terms of the line voltage, current, phase angle and armature constants.

A second set of these V curves is obtainable from the current-power curve; namely, those showing the relation between power factor and field excitation. These are determined as follows: Assume any condition of constant input and let this, as before, be 30 kw.; then refer to the current-power curves, Fig. 20, and multiply the current at any motor e.m.f. by the line voltage. This product is the volt-amperes input, and a division of the corresponding abscissa value (which was 30 kw. input in this instance) by the volt-amperes gives the power factor at the selected field excitation and input. The curves obtained by using the power factor and the corresponding motor e.m.fs. as ordinates and abscissæ, respectively, are those represented by the broken lines in Fig. 24. It is to be noted that these are the converse in shape of the current V curves. The power factor rises with field excitation up to about unity at 500 volts and then falls even more rapidly than it rose as the field strength of the motor is still further augmented. It is also apparent that the power factor of the input is raised by addition of load to the motor.

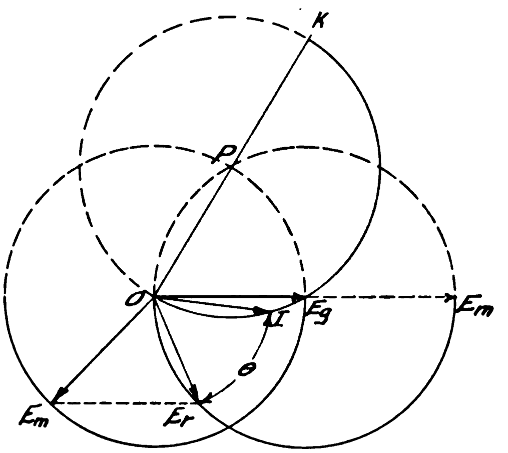

Fig. 23. Circle Diagram of Synchronous Motor; E_g = 500 Volts, E_m = 700 Volts, θ = 60°

Reference to these curves and to the formula for motor e.m.f. (E_m) shows that the smaller values of motor e.m.f. exist when ϕ_g is a lagging angle, because then *sin* ϕ_g is plus and the larger values of the motor e.m.f. exist when ϕ_g is a leading angle, *sin* ϕ_g being then minus, which makes the second term under the radical a larger quantity and consequently E_m greater. Hence, variation of the motor excitation produces a change in the angle between line volts and motor current, low motor excitations causing a lagging current to flow and high excitation drawing a leading current, so that a synchronous motor whose e.m.f. is greater than that of the line (motor super-excited) draws a leading current and acts as if it possessed capacity.

The above property of the synchronous motor, used as such or as a rotary converter, is frequently utilized to improve the power factor of long distance transmission systems, because when energy is supplied to induction motor loads they are apt to produce a very low power factor, necessitating a large lagging current to be transmitted. This condition increases not only the line drop but also interferes seriously with the alternator regulation. The installation of a super-excited synchronous motor at the receiving end of a line reduces this lag of current by drawing a leading current, and the excitation of the motor can be so adjusted that the angle of current lag becomes small.

Balancing Action of Synchronous Motor

The fact that a synchronous motor draws a leading current when super-excited, and that the extent of lead is increased with the degree of super-excitation, gives to this type of polyphase machine the property of restoring a balance to an unbalanced polyphase circuit. When a slightly super-excited motor is connected to the terminals of a balanced or an unbalanced polyphase system all phases of the motor armature draw a leading current. That phase winding, however, which is connected across the line terminals of lower voltage draws a current of greater lead than the other windings because its super-excitation is relatively higher; hence, the compounding tendency of the leading current is more marked in this phase than in the others and the voltage thereof is increased. This action tends to balance the circuit, not only in voltage but in current as well, because the combinations of the leading and lagging currents give reduced resultant currents.

Hunting of Synchronous Motor

A trouble which sometimes arises in connection with synchronous motors is that of *hunting*, *pumping*, or *phase swinging*. By this is meant the periodic fluctuations in speed and armature current occurring under certain conditions. Such surgings may be produced by several causes. Let us suppose the typical motor to be running at a constant load up to a certain instant, and that then the load is suddenly varied, say increased. A momentary retardation of the motor armature naturally results, and we see from the power curves Fig. 17 that the angle between E_m and E_g must decrease to allow of increase in the driving power of the motor. The proper value of armature current is not obtained at the instant that the correct phase angle between E_m and E_g exists, but somewhat later, owing to time lag caused by inertia and the inductance of the armature winding. Thus, while the armature may momentarily pass through the right angular relation with respect to the line e.m.f., it will ultimately draw more current than its load requires. This causes the armature to be accelerated and the angle (δ) between E_m and E_g is increased beyond its proper value, until the driving torque is so much reduced as to be insufficient for the motor load, whereupon lagging or retardation of the armature again ensues, and so on. This *phase swinging* of the armature and *current variation* accompanying it is called *hunting*. The amplitude of this swinging or pendular motion gradually dies down, due to frictional, eddy and hysteretic action and the armature finally finds its correct load position. The irregular rotation above considered may be regarded as consisting of a uniform motion of rotation at synchronous speed with a to and fro or pendular motion superimposed upon it.

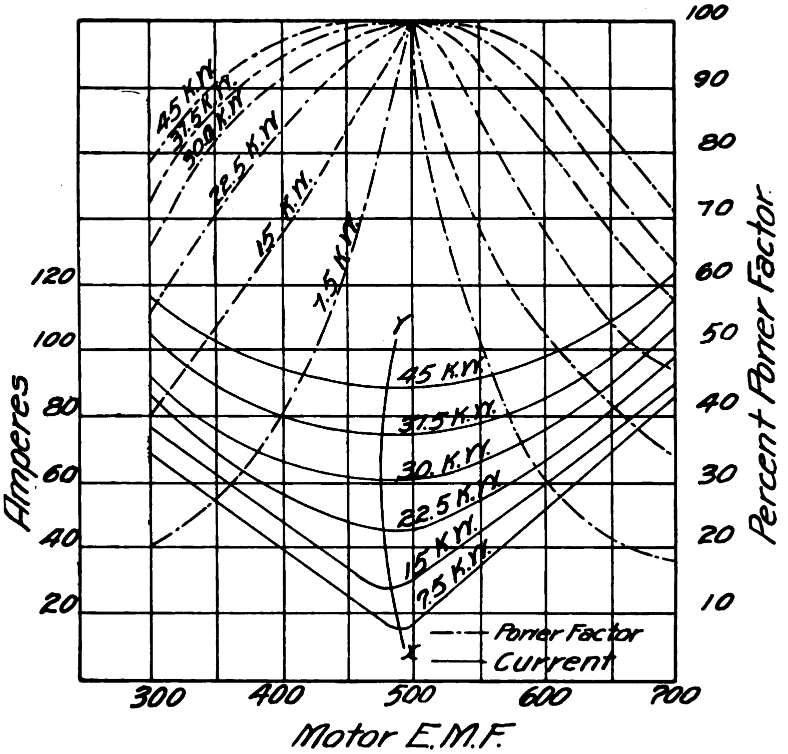

Fig. 24. Curves of 30 Kw. Synchronous Motor

We thus see that a change of load upon a synchronous motor will produce oscillations in its angular velocity and armature current. There are, however, other actions by which such fluctuations may be started. Assume the motor load to remain quite constant, but the speed of the generator to undergo a sudden rise. This corresponds to an advance of the angular position of the line voltage vector, which naturally decreases the angle between E_m and E_g, thus increasing the driving torque of the synchronous motor (see operative-range curves, Fig. 17), and producing an acceleration, which will, as already shown, develop the hunting phenomena. Similarly a sudden change in excitation of the motor or in the line voltage will produce a variation in the motor torque and thus bring about the phase surging action. This fluctuation is very slow compared with the line frequency and its period can be readily determined by the violent swinging of the needle of an ammeter connected in the supply line.

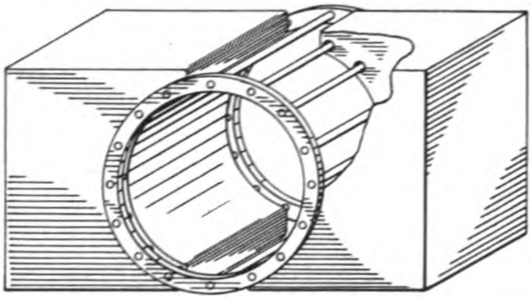

Fig. 25. The Hutin and LeBlanc Amortisseur or Damper

As already stated, the *hunting* started by any one sudden disturbance will gradually subside. If, however, before the oscillations due to one cause have been damped out, another disturbance should occur of such nature as to reinforce the already existing fluctuations, their combined amplitude may become so great as to cause the motor armature to swing beyond the range of stability, with the result that it falls out of step and stops.

This action is likely to occur, because sudden load changes are usually accompanied by marked variations in line voltage, both acting to produce a like effect. The resulting surges of the armature current thus developed may act upon the alternator speed and then all three disturbing factors act in unison. If the phase swinging is not violent enough to cause the motor to pull out of step, the variation thus produced in the line voltage may be, nevertheless, of such low periodicity that it becomes apparent in the flickering of lamps connected to the circuit and it may even develop hunting in other synchronous motors fed thereby. The fact that hunting of a synchronous motor not only affects its own stability but may react upon other synchronous units connected to the line is very objectionable and the prevention of marked hunting becomes a practical necessity.

Prevention of Hunting

Inspection of the power or operation range curves of synchronous motors (Fig. 17) shows that a given change in torque will be obtained with a smaller phase swing when the field is strong than when it is weak, and naturally the smaller the initial phase shift the less the resulting oscillation; hence, use of strong fields is favorable in checking hunting, but this by itself will not suffice.

It has already been indicated that the production of eddy currents by the surging of the armature tends towards the reduction of the duration of the surges, and theoretically any device wherein currents are generated by the pendular motion of the armature will act by Lenz's law to stop the motion producing them. Hence it is necessary to design a device wherein heavy eddy currents are developed by even slight hunting tendencies, in order to arrest the surging in its very development. The devices producing this checking effect are known as *damping coils* or *dampers*. One of the earliest of these dampers was proposed by Hutin and Le Blanc *(Fig. 25), and consists of a series of thick copper bars embedded in each pole piece, parallel to the armature axis, and connected in parallel by heavy copper rings concentric with the armature. A more modern and probably more economical arrangement (Fig. 26), consists of a copper grid placed into corresponding slots cut in the polar faces, the outer rim of the grid forming a closed band around the pole pieces.

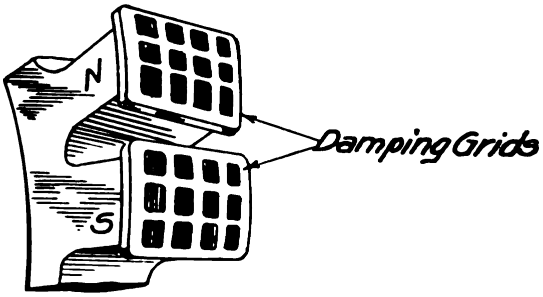

Fig. 26. Damping Coils

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* U. S. Patent No. 529272 Nov. 13, 1894.
* U. S. Patent No. 575116 Jan. 12, 1897.

1200 VOLT DIRECT CURRENT RAILWAY OPERATION

By G. H. Hill

The line potential for direct current electric railroads has heretofore been limited to about 750 volts, in order to secure good commutating characteristics in the motors. The large motors required for modern electric cars, restricted as they are by the limitations of truck dimensions, admit of very little latitude in the electrical design, and commutating stability at a potential greater than 600 volts has been difficult to secure in the standard form of motor, without recourse to impracticable construction.

The development, or perhaps more accurately, the revival of the commutating pole construction, effectually subordinates the question of commutation and opens up new possibilities in high potential direct current railway applications. This construction was proposed many years ago, but at that time commutation difficulties were of minor importance as compared with other troubles in motor construction, and the commutating pole as a practical expedient did not then seem to have sufficient importance to warrant its adoption. Advancement in design has overcome most of these other troubles, and a more complete knowledge of the theory of commutation has brought the commutating pole into the first rank in importance. Having by this means obtained stability with increased potential, it became a relatively simple matter to secure the other elements of design—such as additional insulation and longer creeping surfaces—that are necessary for a successful 1200 volt motor.

The theory, construction and operation of the commutating pole motor has been admirably described by Mr. E. H. Anderson in his article quoted in the February issue of the Review, to which we would refer those interested in the details of design.

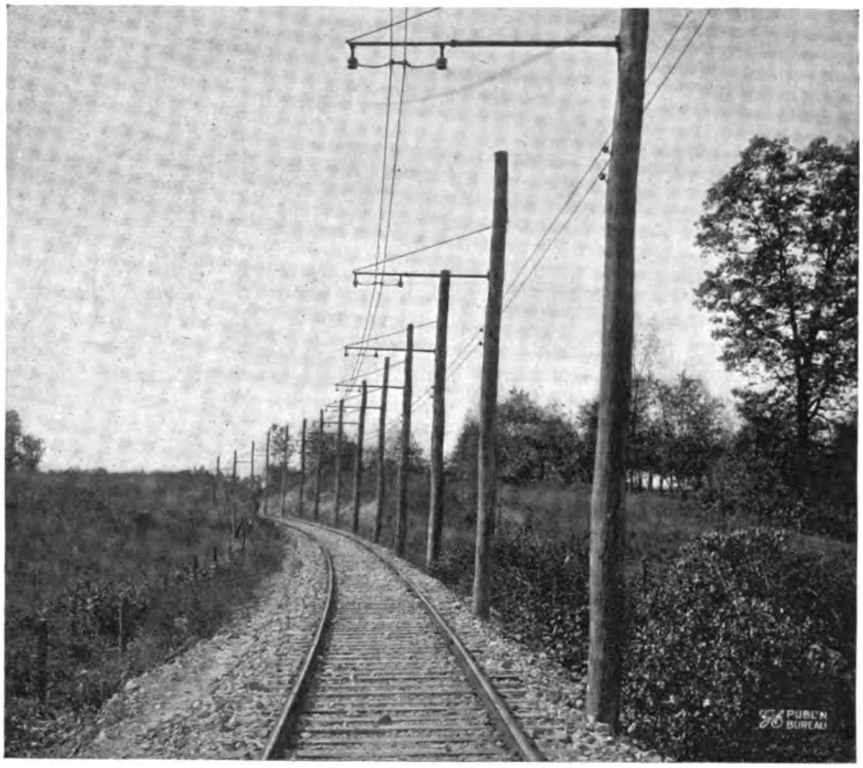


Fig. 1. Curve on the New Castle Section of the Pittsburg, Harmony, Butler and New Castle Railway 1200 Volt D.C. Service

As an initial step in the practical application of higher d.c. voltages, 1200 volts was selected for the following reasons:

1st. Because this potential can be generated by practically standard 600 volt apparatus in series.

2nd. Because, being twice the standard potential, the equipment can readily be operated on the 600 volt terminals of interurban lines, by series paralleling connections.

3rd. Because the economic possibilities with 1200 volts are ample to warrant the establishing of this standard for many classes of railway work.

The advantage in the use of higher potential, whether direct or alternating current, lies entirely in the economic possibilities, as measured by first cost and operating expense of the railway system. The gain arises from the reduction in the number of substations, or in the amount of feeder copper, or both, and is partially offset by the increased cost and weight of car equipment.

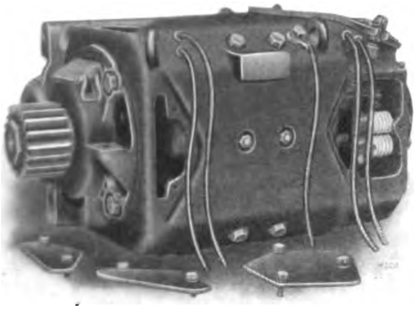


Fig. 2. GE-205 Commutating Pole Railway Motor

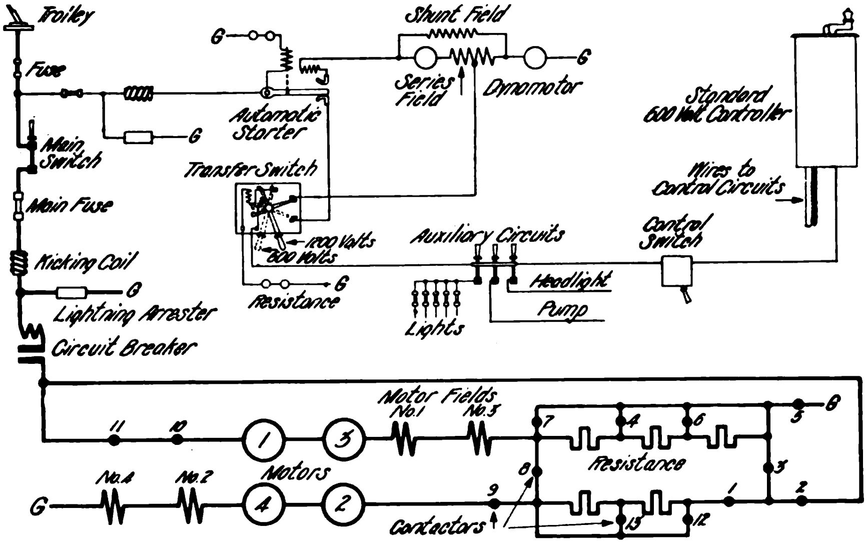

Trolley
Fuse
Main Switch
Main Fuse
Kicking Coil
G
Lightning Arrester
Circuit Breaker
G
G
Automatic Starter
Transfer Switch
1200 Volts
600 Volts
G
Resistance
Shunt Field
Series Field
Dynomotor
G
Standard 600 Volt Controller
Wires to Control Circuits
Auxiliary Circuits
Headlight
Pump
Lights
Control Switch
Motor Fields
No.1
No.5
11
10
1
5
7
4
6
5
G
Resistance
8
3
G
No.4
No.2
Motors
4
2
9
1
2
Contactors
13
12

Fig. 3. General Circuits of 600/1200 Volt Car Equipment

For direct current, the distance to which power may be transmitted over a given line with equal percentage loss, varies as the square of the potential; so that for the usual interurban conditions of schedule in general it may be said that with the same trolley and feeder copper, 1200 volts will operate a line four times as long as one with 600 volts; or it will operate a given line with one-fourth the number of power or substations. In practice the location and number of substations is somewhat governed by local conditions, and the most economical arrangement may include a reduction in the amount of line copper and something more than one-fourth the substations as compared with 600 volts.

With alternating current there is, in addition to the resistance drop in line and track, an inductive drop which, for 25 cycles, approximately doubles that in the line and increases that in the rail about eight times. For this reason a higher potential is necessary with alternating current than with direct, to secure equal distribution losses. It is impracticable, moreover, to allow as high distribution losses in an a.c. system as in a d.c. because of the high reactance and low torque characteristics of the single-phase a.c. motor when starting. As a consequence, considering only the distributing system, an a.c. potential of over 3000 volts is required to obtain the same operating results as are secured with a d.c. potential of 1200 volts.

The car equipment of a 1200 volt d.c. system presents distinct advantages over an a.c.

equipment, in first cost, weight, simplicity, reliability, and cost of operation and maintenance. All things considered, the average interurban road will cost less to install, will be operated for a less amount, and will give a more reliable and satisfactory service when equipped with 1200 volts d.c. than it will with an a.c. system of 6600 or 11000 volts. It is not possible to make an accurate general comparison of the different systems, as local conditions very materially modify the characteristics of the layout, and each case must be studied individually to secure the best result. A great many interurban roads may be served by 1200 volt current directly generated by d.c. machines, while others require three-phase a.c. generation and transmission to substations. Similarly, in some cases, single-phase a.c. current may be generated and distributed without transformers, while in others three-phase generation and transmission to single-phase substations must be employed.

A general comparison of the different systems as applied to an interurban road, is given in the following tabulation:

	600 Volt d.c.	1200 Volt d c.	6600 Volt d.c.
Generators	3-phase	d.c. or 3-phase	3-phase, operating single-phase at about 66% full 3-phase capacity
Transmission	3-phase with step-up transformers	d.c., 1200 volts or 3-phase and step-up transformers	Single-phase direct, or with step-up transformers
Substations	10 to 14 miles apart. Contain step-down transformers and rotary converters.	20 to 35 miles apart. Step-down trans. and rotary converters	25 to 50 miles apart. Step-down transformers Motor generator sets, frequency changers
Trolley Conductor	3rd. rail or trolley	3rd. rail or trolley	Catenary trolley with high tension insulators.

While comparing favorably with single-phase a.c. in the cost, operating expense, and reliability of the generating and distribution system, the superiority of the car equipment of the 1200 volt system gives this system a most pronounced advantage. The importance of this feature cannot be over-estimated.

The 1200 volt car equipment contains no radical departure from 600 volt practice, in design, construction or arrangement. The motor has the same rugged structure, the same capacity for overloads, and the same long life of bearings and brushes as its most successful prototype, the 600 volt motor. The control and auxiliaries are almost identical with a standard 600 volt equipment, with the addition only of the dynamotor, which in actual practice has proven to be thoroughly reliable and economical. The motors may be wound so that each will operate directly on 1200 volts when in parallel, or so that two will be in series when at full speed. In the first case only half speed can be obtained on 600 volt sections; while with the second arrangement, half speed, or, by paralleling the motors, the same car speed as on 1200 volt, can be had on 600 volt sections. Both arrangements are in use, but in most cases two motors in series is preferable.

The superior ability of the contactors of the type M control to handle current made it easy to adapt this control to the requirements of 1200 volt operation, and the development of a complete equipment became largely a question of suitably providing for the car lighting, heating, air compressor and the control circuits.

With the first equipments installed, the convenience of retaining the auxiliary circuit the same as that on the standard 600 volt equipment led to the adoption of the dynamotor to transform the 1200 volt supply to 600 volts. The success of the arrangement was so complete and the operation of the dynamotor so satisfactory that there is little reason, from the standpoint of operation, to make any change in this arrangement. Of the auxiliary circuits, the heaters and air compressor require considerably more energy than do the car lights and the control, and in the larger equipments the amount of energy consumed by the heaters and compressor is considerable. On this account and because the heaters and air compressor lend themselves readily, and without complication of design, to 1200 volts direct, this voltage has been employed for these circuits in recent equipments. The standard arrangement therefore provides a dynamotor for the control and lighting circuits. As the current demand for these is very light, and practically uniform for different cars, the dynamotor is small and the same design is used for all equipments. The arrangement is very flexible for use on both 600 and 1200 volt sections, and requires no complication of circuits and no switching beyond the starting of the dynamotor when entering the 1200 volt section. It removes any question of danger from the use of 1200 volts on the lighting circuits, as well as any complication of the standard fixtures.

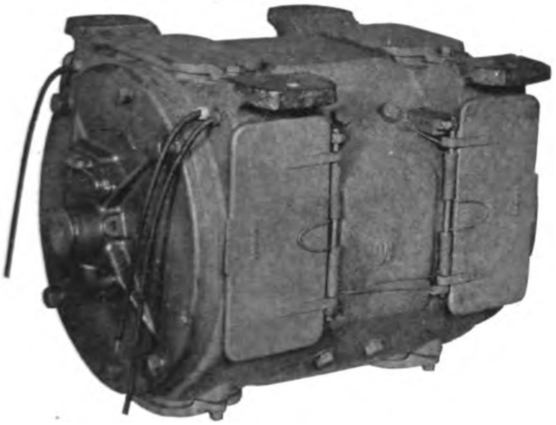


Fig. 4. Dynamotor for Transforming from 1200 Volts D.C. to 600 Volts D.C.

To adopt the heaters to a 1200 volt circuit, it is only necessary to provide the additional insulation required and increase the resistance of the coils to the proper amount. The conductor is completely enclosed and absolutely protected from personal contact. Under the usual conditions of service, it is satisfactory to leave the connections unchanged for both the 1200 volt and the 600 volt section. On 1200 volts the full capacity of the heaters is utilized, while on the short 600 volt sections the less amount of heat is usually satisfactory. Where desirable, the heaters can be arranged for series parallel connections so as to give full capacity on both sections.

The 1200 volt air compressor has been found very satisfactory. The motor has a single commutator and is of the non-commutating pole series type. By very conservative design, the commutation is excellent on 1200 volts.

No change in connections is made in passing from the high voltage to the low voltage or vice versa. The amount of air required on the interurban section where whistle signals are used will be very nearly as great as on 600 volt city sections having a greater number of stops but no whistling. On 1200 volts the compressor will operate with the usual number of stops about 35 per cent. of the total time. On city sections it will run at about half speed and about 70 per cent. of the time. The compressor is controlled by the usual form of governor properly arranged for 1200 volt service.

The dynamotor consists of a single field and an armature body with two identical armature windings and commutators. The two armature windings are in series across the 1200 volt line, and a shunt field is provided for excitation. An auxiliary circuit tap is made in the center of a series field winding connected between the armatures as shown in the diagram of general circuits. When the dynamotor is started, current from the line flows through the series turns strengthening the field and enabling the machine to start without sparking or taking a large current. When current flows to the auxiliary circuit, part of it is drawn from the line through the first armature and half the series turns, and part is drawn from the second armature, which is acting as a generator, and flows through the second half of the series turns in the opposite direction to the current in the first half; the

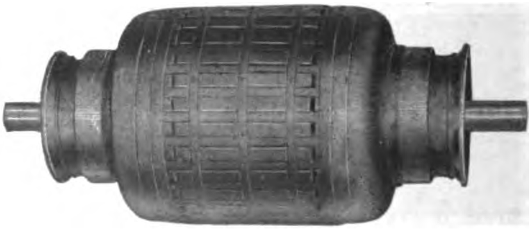


Fig. 5. Armature of Dynamotor

effect of the series winding is thus neutralized.

The series winding has another important function. In case line current fails, as when the trolley leaves the wire, the dynamotor, revolving by its own momentum, generates current which flows through the main circuit to the driving motors of the car; without some means of limiting it, this current would be sufficient to blow the dynamotor fuse or cause violent overload and arcing. Such generated current, however, flows through all the series turns in the reverse direction to the current in the shunt field, and destroys the field excitation of the machine, thus damping out its generated current.

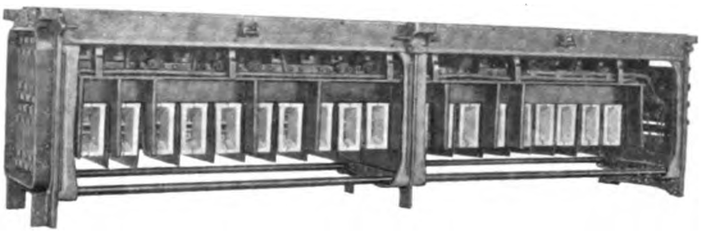


Fig. 6. Contactor Box with Contactors in Place

The dynamotor is completely enclosed, and as there is no torque transmitted through its shaft, there is little or no wear of the bearings. Deep oil wells and ring oilers are provided, and the care and maintenance are negligible.

The contactor which starts the dynamotor is so wound as to be inoperative on 600 volts, but actuated by 1200 volts; so that the dynamotor starts automatically when the car passes on to the 1200 volt section. The transfer switch rests normally in its 1200 volt position, and is moved by the motorman to the 600 volt position and held there by a magnetic latch. When the car passes over the trolley gap from the 600 to the 1200 volt section, this latch is released, and the transfer switch is automatically moved by its spring to the 1200 volt position. In passing therefore, from the 600 to the 1200 volt section the dynamotor is started and the transfer made automatically. In passing from the 1200 to the 600 volt section, the motorman throws over the transfer switch.

The success of the 1200 volt system has been most gratifying, especially since it has established itself in practical and permanent form without extensive experimentation and changes, which are expensive and annoying both to the manufacturer and customer.

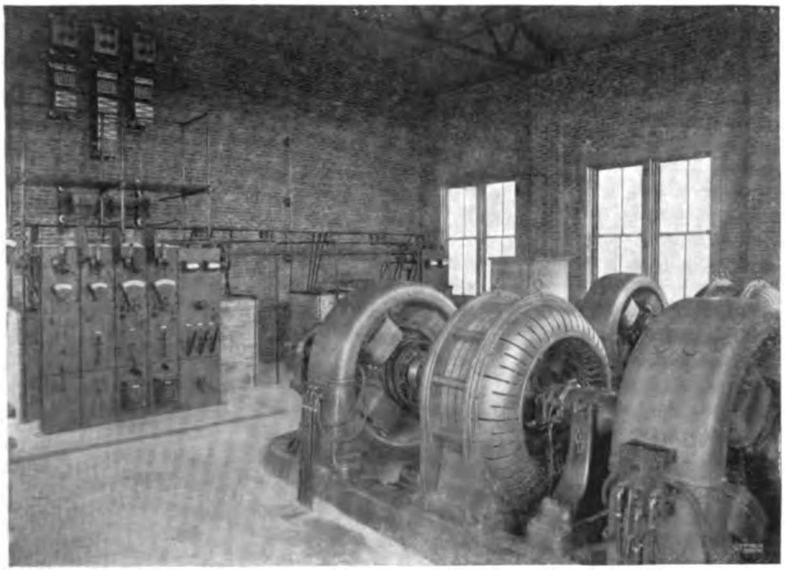


Fig. 7. Interior of Shenango Substation

RECENT DEVELOPMENTS IN SMALL MOTORS

By H. S. Baldwin

It happens that the new alternating and direct current fractional horse-power motors, recently placed on the market by the General Electric Company, have a distinguishing peculiarity common to all, and this has furnished the name "drawn shell." A name descriptive of their superior electrical design would undoubtedly have been more appropriate and preferable; but, as is frequently the case in matters of this kind, the name attaches itself. There is some reason for this, since the new motors have their field and stator iron securely bound in shells, drawn from plates of steel. (Fig 3.)

With this word of explanation, it may be of interest to review briefly the progress of the electric motor through the comparatively few years which have passed since it took its place as a motive device linked by a wire to the prime mover, thus setting in motion the distant wheels of industry.

The electric motor of today came into practical use in the latter eighties. There were, of course, many earlier motors, but for the most part their field of activity was confined to purely scientific research and did not extend to the arts. In 1881 the arc light began to appear on city thoroughfares, and about 1884 electric motors were first employed to propel street railway cars. It is thus seen that the use of electricity for public utilities created a demand for electrical energy which was quickly met by the springing up of power plants in the cities and towns throughout the country. With the arc light came the incandescent lamp, introducing electricity into the home and extending its use in places of business. There was wide-spread interest in the energy that gave both power and light; progress was rapid; and it was soon apparent that the electric motor could be used to great advantage in operating the machinery of factories. Among the earlier stationary motors, many were of comparatively large size, perhaps 10 to 25 horse-power.

The desire for comfort has led man to devise many ingenious applications of the electric motor, and it is not strange that the attachment of a fan to the shaft of the small motor to furnish artificial draft in the hot summer season should suggest itself. Sewing machines had been in use in the home for many years, and here again was an opportunity to use the small high speed motor, and to lessen the burden of the housewife. It is natural and logical, therefore, that the electric fan and the sewing machine motor should be found as perhaps

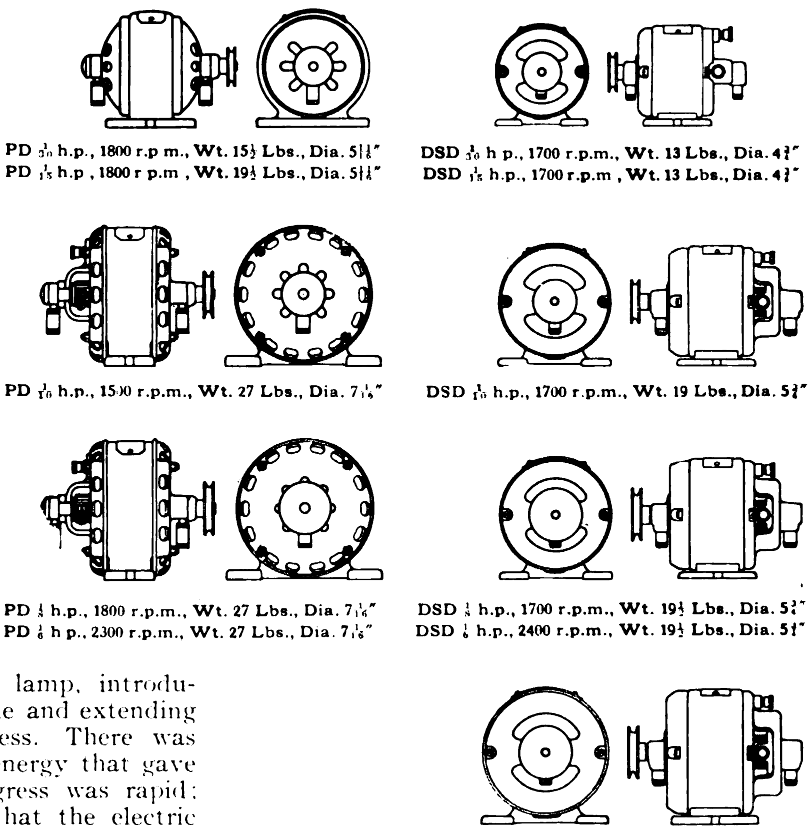


Fig. 1. COMPARATIVE OUTLINES OF DIRECT CURRENT MOTORS

TYPE PD MOTORS

PD $\frac{1}{30}$ h.p., 1800 r.p m., Wt. $15\frac{1}{2}$ Lbs., Dia. $5\frac{11}{16}$"
PD $\frac{1}{15}$ h.p , 1800 r p.m , Wt. $19\frac{1}{2}$ Lbs., Dia. $5\frac{11}{16}$"

PD $\frac{1}{10}$ h.p., 1500 r.p.m., Wt. 27 Lbs., Dia. $7\frac{1}{16}$"

PD $\frac{1}{8}$ h.p., 1800 r.p.m., Wt. 27 Lbs., Dia. $7\frac{1}{16}$"
PD $\frac{1}{6}$ h p., 2300 r.p.m., Wt. 27 Lbs., Dia. $7\frac{1}{16}$"

TYPE DSD MOTORS

DSD $\frac{1}{30}$ h p., 1700 r.p.m., Wt. 13 Lbs., Dia. $4\frac{3}{4}$"
DSD $\frac{1}{15}$ h.p., 1700 r.p.m , Wt. 13 Lbs., Dia. $4\frac{3}{4}$"

DSD $\frac{1}{10}$ h.p., 1700 r.p.m., Wt. 19 Lbs., Dia. $5\frac{3}{4}$"

DSD $\frac{1}{8}$ h.p., 1700 r.p.m., Wt. $19\frac{1}{2}$ Lbs., Dia. $5\frac{3}{4}$"
DSD $\frac{1}{6}$ h.p., 2400 r.p.m., Wt. $19\frac{1}{2}$ Lbs., Dia. $5\frac{3}{4}$"

DSD $\frac{1}{4}$ h.p., 1700 r.p.m., Wt. $23\frac{1}{2}$ Lbs., Dia. $6\frac{1}{2}$"

the earliest applications of what are termed fractional horse-power motors.

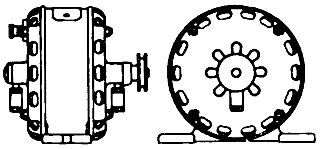
About 1893-5 the General Electric Company investigated the possibilities of the electric fan, and placed one of the direct current type on the market. With a small, well designed motor available, other fields of usefulness were opened up, and the little fan motor became a power motor a few years later.

The next step was the introduction of the alternating current, and with it came a single-phase induction motor for sewing machines, followed a little later by a motor designed for power purposes. Since the first induction motor was intended primarily for operating a fan, it was made as simple and cheap as possible. It had what are known as pronounced poles, with shading coils to insure starting. The second motor, however, was built along more modern lines, with a view to greater starting torque and higher efficiency. It had a distributed winding, a resistance coil in the base for starting, and was equipped with an automatic switch and a centrifugal clutch. In many ways this was an excellent motor, and today many thousands are in use throughout the world. This may be termed the prototype of the small induction motor of today, and served as a model for similar motors, later placed on the market by other electrical manufacturers.

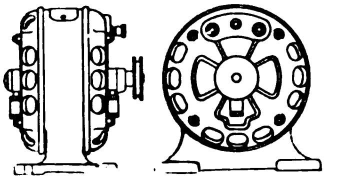
These motors met commercial demands for several years. With the many modern requirements, however, it was recognized that the old line should be redesigned, and that there should be a greater variation in dimension for the several ratings. It had previously been the practice to change the thickness of active iron, also the winding, retaining, however, the same diameter of magnet frame. This caused motors of small rating to appear of nearly the same size as those of larger power, and did not permit of fine gradation of cost to meet actual market conditions.

Fig. 2. COMPARATIVE OUTLINES OF ALTERNATING CURRENT MOTORS

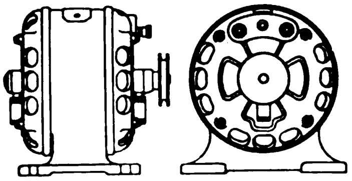
TYPE PA MOTORS



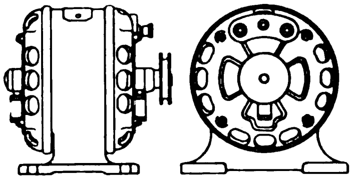
PA 1/30 h.p., 1800 r.p.m., Wt. 23½ Lbs., Dia. 7 1/16"



PA 1/15 h.p., 1800 r.p.m., Wt. 26½ Lbs., Dia. 7 9/16"
PA 1/10 h.p , 1800 r.p.m., Wt. 30 Lbs., Dia. 7 9/16"

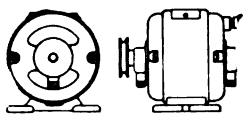


PA ⅛ h.p., 1800 r.p.m., Wt. 34½ Lbs , Dia. 7 9/16"

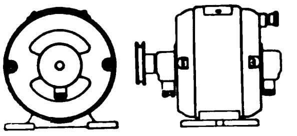


PA ⅙ h.p., 1800 r.p.m., Wt. 34½ Lbs., Dia. 7 9/16"

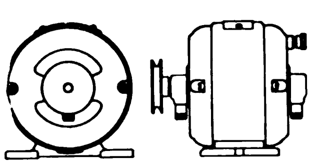
TYPE DSS MOTORS



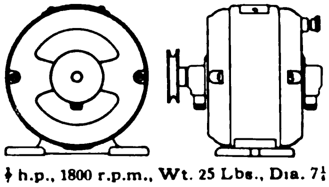
DSS 1/30 h.p., 1800 r.p.m., Wt. 13 Lbs., Dia. 4¾"



DSS 1/15 h.p., 1800 r.p.m., Wt. 19 Lbs., Dia. 5¾"
DSS 1/10 h.p., 1800 r.p m., Wt. 21 Lbs., Dia. 5¾"



DSS ⅛ h.p., 1800 r.p.m., Wt. 26 Lbs., Dia. 6½"



DSS ⅙ h.p., 1800 r.p.m., Wt. 25 Lbs., Dia. 7¼"
DSS ¼ h.p., 1800 r.p.m., Wt. 30 Lbs., Dia. 7¼"

As has already been stated, a new line of motors has now been developed, and the accompanying comparative outlines will give an idea of the old and the new. (Figs. 1 and 2.)

The drawn-shell motors, so-called, are designed with special care as to electrical characteristics and mechanical features. The induction motors have high power factor, efficiency, and liberal overload capacity, with moderate heating (see Figs 4 and 5). They are light in weight and of fine workmanship. The windings are of the concentric type, and the starting coils are automatically cut out by a switch at the proper moment. A centrifugal clutch is furnished when necessary. The magnet frames of both direct and alternating current motors are cylindrical, having no lugs or projections whatsoever. They may therefore be said to be universal, since they can be fitted with ease to any form of support, and the heads may be turned to any quarter;

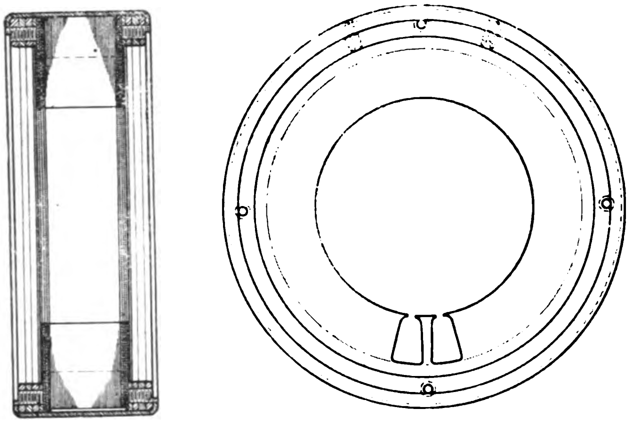


Fig. 3. Construction of Motor Field

that is, the frame can be turned to permit the motor to be inverted, or attached to a wall or vertical bracket. The standard base is shown in the comparative outlines, and this is held in place by two screws tapped into the magnet frame. The direct current fields are built up of punchings, a construction which secures much smaller diameters than is possible with the usual cast steel or iron magnet frames. Field and stator punchings are assembled under compression, with thick punched rings to serve as spacers for the end turns of the windings, and the whole is pressed into a steel shell. The edge of the shell is spun over, securely holding the iron in place. This construction eliminates the outside frame of cast iron that is usually employed, as well as the necessity for all holes through the active iron; and makes possible accurate methods of manufacture, which insure perfect concentricity of parts and an alignment not usually found when the common cast shell is used. The drawn shell also permits of somewhat smaller outside diameter than does the cast frame. All punchings of active iron are made with compound dies and are assembled on accurate expanding plugs, where they remain until pressed into the shell and secured by spinning over the edge. The frame is then placed on an arbor, and the rim trued and grooved to receive the heads, which are made of cast iron. These are machined on centers to fit the frame; consequently the whole structure of the motor is correct, and accurate air gap and alignment of bearings are the result. The shafts of all motors are of good dimensions, and the bearing linings are of bronze. The smaller sizes are wick-oiled from below. All parts are made interchangeable by means of jigs and fixtures.

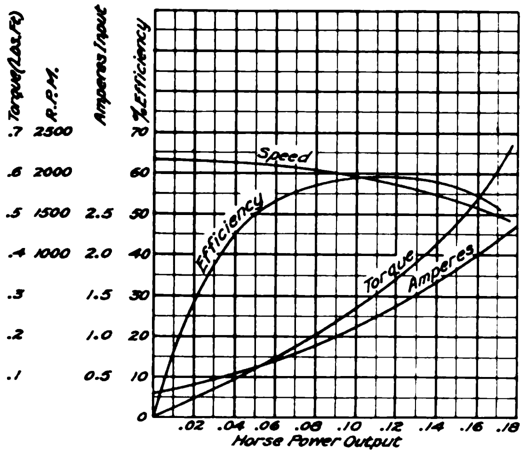


Fig. 4. Typical Curves of Direct Current Motors

The type letters DSD and DSS have been assigned to designate the direct and alternating current motors respectively. The drawn shell motors are now in production, and initial sales indicate that they meet the

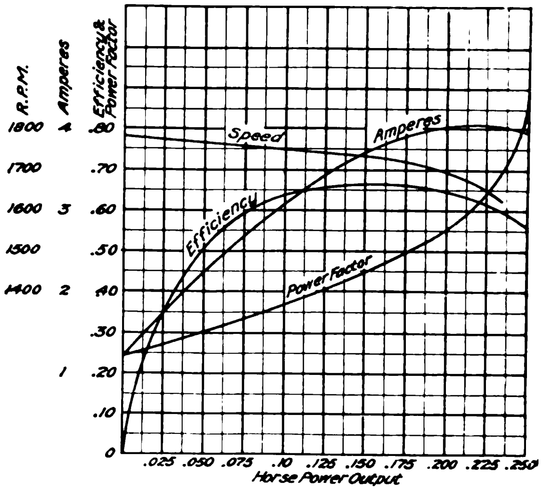
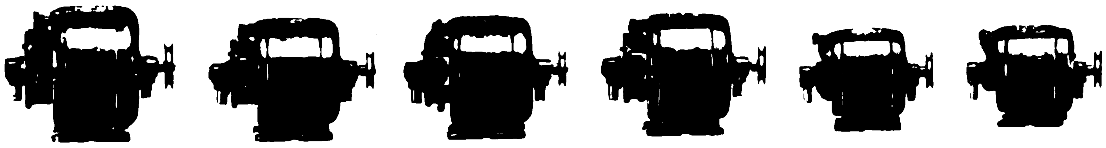


Fig. 5. Typical Curves of Alternating Current Motors



¼ h.p., 1700 r.p.m. ⅙ h.p., 2400 r.p.m. ⅛ h.p., 1700 r.p.m. $\frac{1}{10}$ h.p., 1700 r.p m. $\frac{1}{12}$ h.p., 1700 r.p.m. $\frac{1}{20}$ h.p., 1700 r.p.m.

Fig. 7. Complete Line of Direct Current Motors

demand of the trade in a highly satisfactory manner. They are supplied to meet all commercial circuit conditions of voltage and current, and, in the case of induction motors, can be had for the several frequencies with single or polyphase windings. It often happens that the user desires direct and alternating current motors of the same dimensions; so that they may be used interchangeably on certain kinds of apparatus. It will be seen from the comparative table that this requirement can readily be met by interchanging an alternating current motor with a direct current motor of next larger capacity. This advantage is peculiar to the new line of motors, and is of great value in their application to the many modern household conveniences now available.

Figs. 7 and 8 are taken from actual photographs and convey a good comparative idea of the direct and alternating current motors of the several sizes.

Fig. 6 represents an attractive motor-generator set of small size and gives some idea of the possibilities opened up by the new motors with true cylindrical bodies.

Another interesting application is illustrated in Figs. 9 and 10, which show the smallest motor in connection with the new General Electric sewing machine attachment. The design of this device is extremely simple and it can be attached to any machine of the usual construction in a few minutes. As

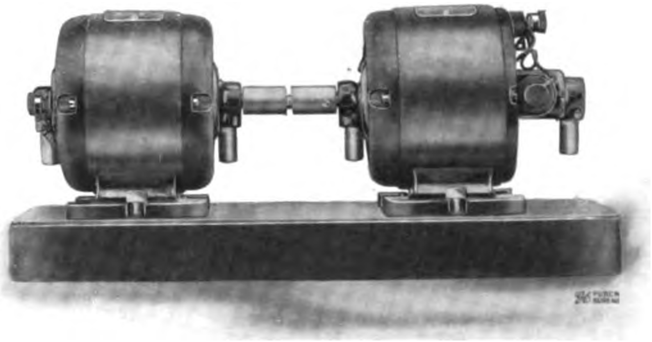
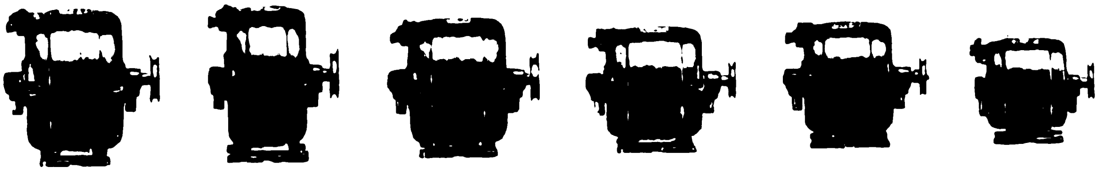


Fig. 6. Motor-Generator Set



¼ h.p., 1800 r.p.m. ⅙ h.p., 1800 r.p.m. ⅛ h.p., 1800 r p.m. $\frac{1}{10}$ h.p., 1800 r.p.m. $\frac{1}{12}$ h.p., 1800 r.p.m. $\frac{1}{20}$ h p , 1800 r.p.m.

Fig. 8. Complete Line of Alternating Current Motors

previously pointed out, the motor may be for alternating or direct current, according to conditions. The attachment comprises the operating switch, cable and socket, so that anyone without special mechanical or electrical knowledge can immediately install the motor. An advantage, not found in other devices of a similar nature, lies in the fact that no part of the sewing machine whatsoever is disturbed in order to equip it with the electric motor; that is, it is not necessary to remove, for example, the fly wheel connecting rod, or parts of the frame. It will readily be seen that the motor, which is itself of small dimensions, is placed on a line with the handwheel of the sewing machine, and a minimum of space on the table is required for the swivel base. Sewing is accomplished by turning the switch and depressing the pedal in the usual manner; thereby removing the friction brake, which is clearly indicated, and increasing the tension of the driving belt, the whole attachment rocking about the pivot which will be seen directly below the motor. When pressure of the foot on the pedal is removed, a coiled spring in the base of the attachment causes the tension on the driving belt to be relieved and the brake to be applied to the handwheel. This method of control is so positive and simple that it is not necessary for the operator to remove her hands from her work. It sometimes occurs that the pulley of the sewing machine is on the outside of the handwheel, in which event provision is made for change of location of the small driving pulley. When it is desired to lower the head, or place the cover on a stationary head machine, the attachment can be turned to one side, by withdrawing the indexing pin shown close to the table. If the machine is not to be used for a considerable period of time, the complete attachment can be removed, leaving only the small plate, which is not objectionable in appearance.

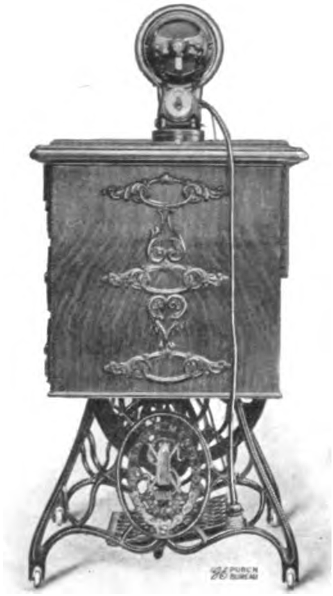


Fig. 9. End View of Sewing Machine with Motor in Operating Position

These are only a few of the many applications brought about by the increasing use of electricity in home and shop.

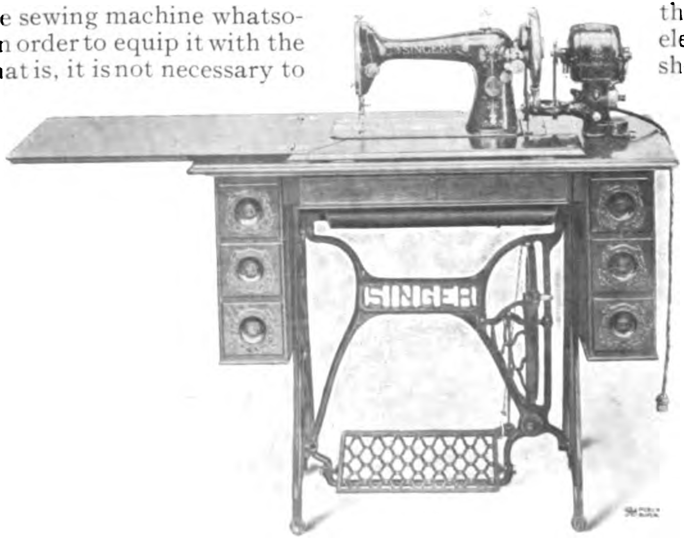


Fig. 10. Motor and Attachment in Operating Position on Sewing Machine

FEEDER REGULATORS AND THEIR IMPORTANCE IN A.C. SYSTEMS OF DISTRIBUTION

By F. W. Shackelford

The subject of good voltage regulation has always been of exceptional importance to central station managers, and with the advances which have recently been made in the application of electricity and the art of illumination, this question becomes of even greater consequence to those interested in distributing electric current.

In large cities it has generally been the practice to supply that section of the city known as the business centre (and the immediate neighborhood) with a network of direct current feeders, which, when properly designed, give a fairly good voltage regulation; but with A.C. systems covering a large area it becomes essential to regulate the feeders separately. In cities where alternating current is used entirely and where central stations supply both light and power from one common bus, it is absolutely necessary that the feeders, or at least the principal ones, be adjusted individually.

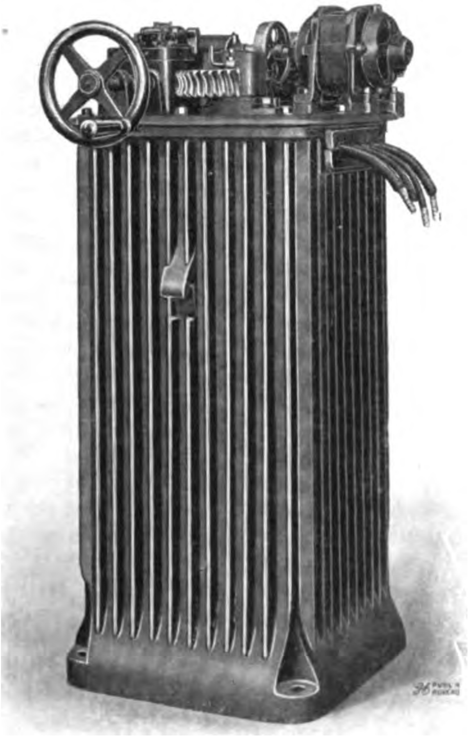


Fig. 1. Single-Phase Induction Regulator

Voltage regulation is not only essentially the measure by which a customer judges the excellence of a system, but determines in no small degree the economy with which that system is operated. This fact is true of any electrical distribution, but is probably better appreciated when a purely lighting system is considered, in which some of the results of good voltage regulation are:

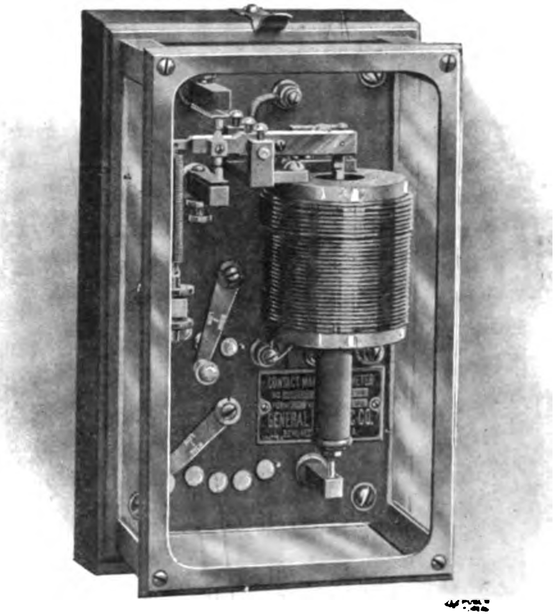


Fig. 2. Contact-Making Voltmeter

- Satisfied customer
- Decreased lamp renewals
- Increased sale of energy to customers
- Increased efficiency of the entire system.

No pains are spared to insure good regulation of prime movers for the driving of electric generators, and careful study of generator design has made it possible to produce machines with excellent regulating qualities; but no matter how perfect the regulation of the generator, there will invariably be unequal voltage at the different feeders resulting from fluctuating loads at the points of distribution.

Such fluctuations may be gradual as in the case of large lighting (exclusively) systems, or they may be rapid as in the case of stations with mixed loads.

Feeders of widely varying characteristics as regards load and length are often fed from a common bus, and since, as we have seen, it is essential to regulate, it becomes necessary to employ some device which will give to each feeder its proper delivery voltage.

Several devices have been employed for this purpose, some utilizing the principles of the series resistance, others using a simple compensator; but it has been found most economical to use a variable ratio transformer, placing the secondary in series with and the primary across the feeder to be regulated.

The secondary coil of such a transformer can be divided into a number of taps so that equal increments of voltage may be added, up to the limit of the regulating transformer capacity. Such a regulating device can be actuated by hand, necessitating the careful attention of the operator, or it can be motor driven, in which event almost as much attention is required as when operated by hand; or again, it can be automatically operated, an initial adjustment of compensating and contact making devices being all that is required.

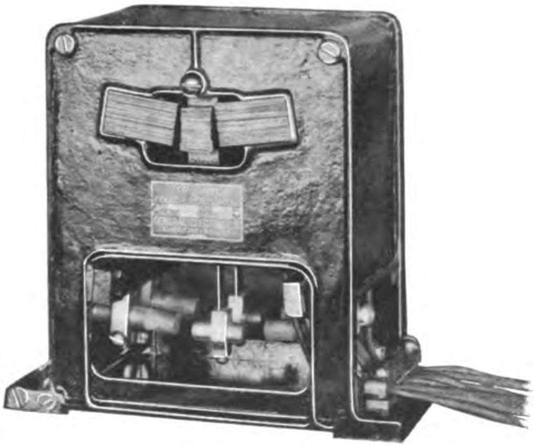


Fig. 3. Relay Switch

The latter method should appeal to all central station managers, inasmuch as such a device is always on duty and not dependent for its successful operation on the switchboard attendant, who may have many other duties to perform.

Feeder regulators can be applied to any primary system of distribution, and it may be well to illustrate this point to some extent.

The single-phase system of distribution is very simple and has been widely used in the past, but is now almost entirely abandoned on account of its not being well adapted to power load. In such a system it is only necessary to supply one single-phase regulator to each feeder.

The two-phase system of distribution may be divided into two classes; *i.e.*, two-phase three-wire, and two-phase four-wire. The two-phase three-wire system possesses an advantage over the single-phase in that it can take care of a power load as well as a lighting load. In applying regulators to such a system it is necessary to use two single-phase regulators, since under certain conditions the load on one phase tends to unbalance the voltage of the other phase.

The two-phase four-wire system, which is established by inter-connecting the phases at the middle point or by maintaining the phases entirely separated, is an improvement over the two-phase three-wire system. It is preferable to operate the phases entirely separated, and the application of regulators is made by installing a single-phase regulator on each phase in cases when the phases are not balanced, and by using a quarter-phase regulator where the phases are practically in balance. In some stations it is advantageous to use both methods of regulating, though this is an exception to general practice.

The three-phase system of distribution can be either three-wire or four-wire. In applying regulators to a three-phase, three-wire system it becomes necessary, in case the three phases are unbalanced, to employ three single-phase regulators, one in each phase. Whereever practicable, however, it is advisable to use only one phase of a three-phase feeder to handle the lighting load, installing a regulator in this phase and letting the other two phases shift for themselves. Where a three-phase power load is regulated, it is desirable to distribute the load so as to maintain as nearly as possible a balanced system and therefore to use a three-phase regulator for controlling it.

Where the three-phase four-wire system is used, it is generally necessary to employ single-phase regulators, one in each leg, operating between this leg and the neutral wire. However, by properly balancing, it is possible to employ a single three-phase regulator on each feeder.

The General Electric Company manufactures two feeder regulators that can be operated automatically, one being of the induction type and the other of the switch type.

The induction regulator is built in both the single and polyphase types, and its automatic operation is effected by an auxiliary contact-making voltmeter, so connected to a potential and current transformer that a rise or fall of line voltage from a predetermined value will cause contact to be made in a relay switch, this in turn closing the circuit of a small motor which is mounted directly on top of the regulator case, and which drives the regulator armature by means of suitable gearing. Such a regulator is shown in Fig. 1. The primary contact-making device is shown in Fig. 2 and the relay switch in Fig. 3. The complete connections of an automatically operated single-phase induction regulator is shown in Fig. 4. The regulator comprises two separate and distinct wirings arranged on concentric laminated iron cores; the primary or shunt winding being mounted on a vertical shaft which can be partially rotated and which is enclosed by and separated from the secondary or series winding by a small air gap. The shunt winding produces a magnetic flux that has a constant value, the direction of which is fixed with relation to the movable core, but variable with respect to the secondary core and consequently with respect to the series or stationary winding. This flux, when passing through the secondary coils in one direction, induces a potential in these coils which is added directly to the line potential, or which, when the direction of the flux is reversed by rotating the primary core through an angle of 180 degrees, is subtracted from the line potential.

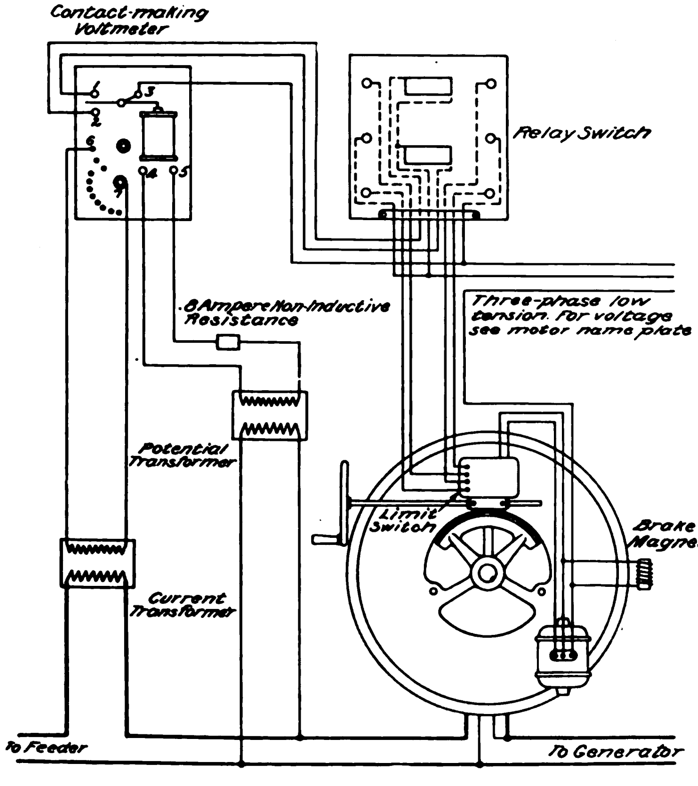

Contact-making Voltmeter
Relay Switch
8 Ampere Non-Inductive Resistance
Three-phase low tension. For voltage see motor name plate
Potential Transformer
Limit Switch
Brake Magnet
Current Transformer
To Feeder
To Generator

Fig. 4. Connections of Single-Phase Induction Regulator with Compensating Device for Automatic Operation

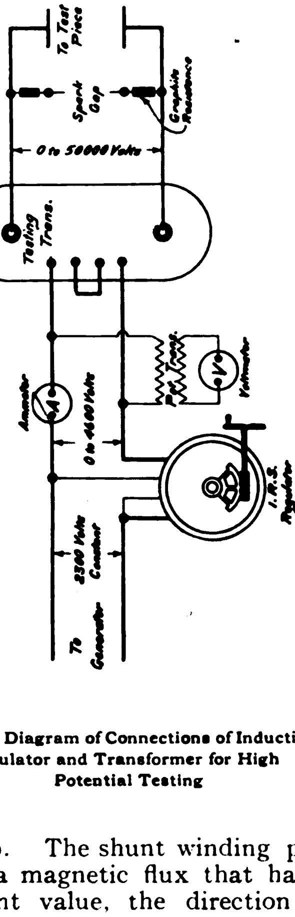

To Test Piece
Spark Gap
Graphite Resistance
0 to 50000 Volts
Testing Trans.
Ammeter
0 to 4600 Volts
Pot. Trans.
Voltmeter
I.R.S. Regulator
2300 Volts Constant
To Generator

Fig. 5. Diagram of Connections of Induction Regulator and Transformer for High Potential Testing

It will therefore be seen that as the primary core is rotated gradually, the direction and amount of the flux is varied, this variation producing a graduated potential in the secondary from maximum boost, through zero, to maximum buck. These windings are incased in a rectangular corrugated cast iron tank, the tank being filled with oil up to the level of the winding. The design permits of a free circulation of the oil, and the corrugated tank easily radiates the heat. The operating mechanism, with the exception of the contact-making voltmeter and relay switch, is mounted on the cover; the voltmeter and relay switch being mounted in the most convenient location. This regulator gives a gradual increase or decrease of voltage, in accordance with the requirements of the feeder, and its operation is rapid enough to control a most widely fluctuating circuit.

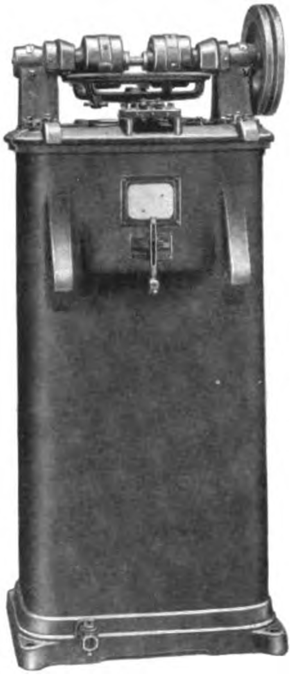


Fig. 6. BR, or Switch Type of Regulator

Due to the properties of this regulator for producing a gradual increase or decrease in voltage, it is quite often employed in conjunction with a transformer for high potential testing purposes. The connections of such a testing outfit are shown in Fig. 5.

The switch, or BR type of regulator is essentially a single-phase regulator consisting of a primary and a secondary coil. The secondary coil is provided with taps, these taps being connected to a cylindrical metal pot provided internally with copper contact strips. Within this cylinder is a movable arm carrying ten contact fingers, and a stationary cylinder composed of ten collector rings, the arm being connected to a vertical shaft and rotated in either direction by means of bevel gears actuated by magnetic clutches. An idea of the construction of this regulator can be gained from Fig. 7. Its general external appearance is shown in Fig. 6. The moving part has but little inertia and can be rotated from maximum boost to maximum lower in from three to five seconds. This type of regulator is admirably adapted for use on feeders where fluctuations in voltage are exceedingly rapid.

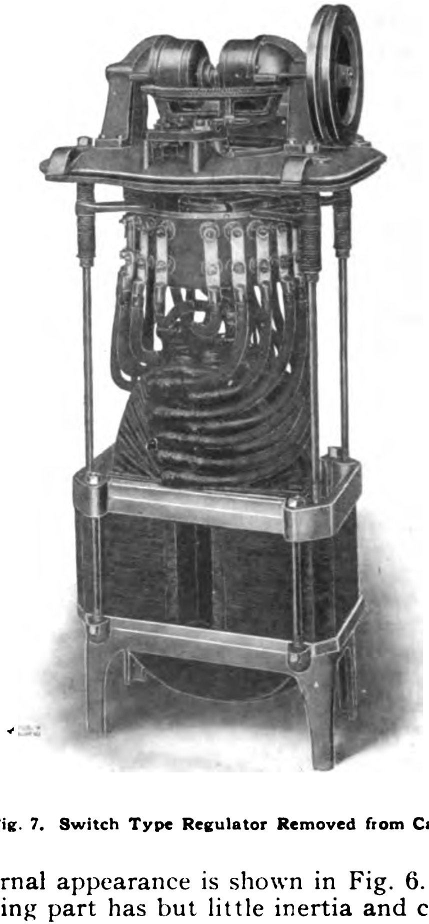


Fig. 7. Switch Type Regulator Removed from Case

REGULATORS FOR ALTERNATORS

By H. A. Laycock

Power and Mining Engineering Department, General Electric Company

The regulators to be considered in this article are the TA Form A-2, which is the standard alternating current regulator for small capacities; the TA Form F-2 to 12, which are similar to the TA Form A-2 in operation, but intended for larger capacities; and the TA Form K.

Principles of Construction

In Fig. 1 an elementary diagram of the TA Form A-2 regulator and its connections with the alternator and exciter are shown. The regulator contains a direct current control magnet and a relay, the former being connected to the exciter bus bar. This magnet has a fixed core at the bottom and a movable core at the top, the latter being attached to a pivoted lever, on the opposite end of which is arranged a flexible contact. Opposite the direct current magnet is the alternating current control magnet, which is provided with a potential winding connected through a potential transformer to the alternating current generator or bus bars. In addition, the control magnet is provided with a compensator winding which, in the diagram of Fig. 1, is shown connected to the current transformer placed in the principal lighting feeder. This compensating winding is adjustable, so that any degree of compensation from 1 to 15 per cent. may be obtained, depending on the line requirements. The core of this magnet is movable and is attached to a pivoted lever, on the opposite end of which is arranged a contact similar to that of the direct current magnet, and in combination with which it forms what are known as the floating main contacts. These contacts control one of the differential windings of the relay, the other winding being permanently connected across the exciter bus bars, as shown.

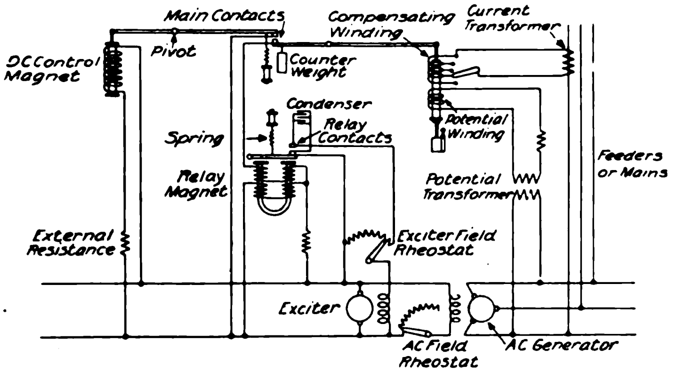


Fig. 1. Elementary Diagram of TA, Form A Regulator

The relay windings have a U shaped magnet core and a pivoted armature, the latter controlling the relay contacts which are connected across the exciter field rheostat. To prevent destructive sparking at these contacts, condensers are connected across them, as shown in the above mentioned diagram.

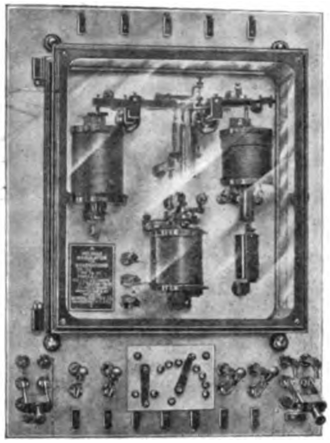


Fig. 2. Front View of Type TA, Form A-2 Regulator

Cycle of Operation

The shunt circuit across the exciter field rheostat is opened, by means of a single pole switch located at the bottom of the regulator, and the rheostat is set until the alternating current voltage is reduced 65 per cent. below normal. This reduction in voltage will weaken the alternating current magnet, whereupon its core will fall and cause contact to be made with the upper main contact carried by the direct current main control magnet. This latter magnet has also been weakened, and allows a spring to pull down its contact lever, thus effecting a definite closure of the floating main contacts. The closing of these contacts completes the circuit of the other winding of the relay, the magneto-motive force of which opposes that of the permanently connected winding, thus demagnetizing the relay core and releasing the armature. With the release of the armature the relay contacts are closed, due to the action of a spring connected to the armature. Then, upon closing the single pole switch, thus allowing the relay contacts to short circuit the exciter field rheostat, the voltage of the exciter will immediately rise, and consequently that of the alternating current generator. As these voltages rise, the alternating and direct current control magnets will be strengthened, and at that voltage for which these magnets have been previously adjusted by the counterweights the main contacts will separate, thus opening one of the relay windings and allowing the full magnetizing effect of the other winding to act upon the relay core. The result of this will be to again throw the full resistance into the exciter field circuit and thus lower the alternating voltage.

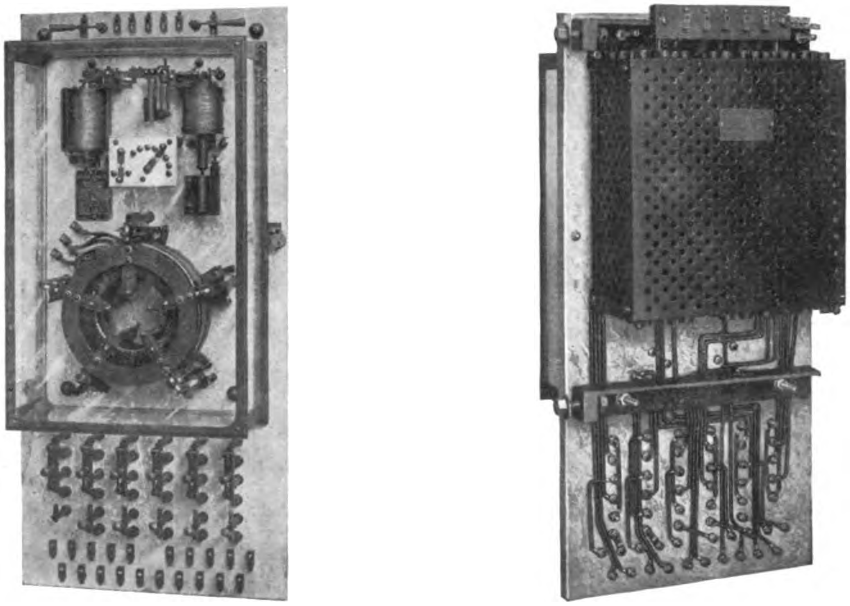
Due to the sensitive direct current control magnet, this cycle of operation is effected at a high rate of speed, with the result that the contacts are in a continual state of vibration. It will therefore be seen that not a constant but a steady exciter voltage is maintained, which will increase or decrease according to the demands of the alternating current system, a change in the voltage of which tends to weaken or strengthen the alternating current control magnet.

The regulation being effected entirely in the field circuit of the exciter, the system operates at the highest efficiency and eliminates the enormous losses resulting from operating directly on the generator field.

Description of Regulators

A front view of this regulator is shown in Fig. 2. As stated before, this regulator is designed for use with alternating current generators provided with exciters of small capacity.

The Type TA Form 5 regulator is shown in Figs. 3 and 4. Regulators of this type are designed with relays varying in number from 2 to 12, depending on the size, capacity and characteristics of the exciters used. Their principle of operation is the same as that of the Form A-2 previously described.



Figs. 3 and 4. Front and Back Views of Type TA Form F-5 Voltage Regulator

Fig. 5 shows the complete internal connections of the relay, and Fig. 6 one arrangement of the external connections.

From these diagrams, it will be seen that many combinations can be made with these types of regulators to meet the requirements of different plants.

These regulators may be mounted on brackets at either end of the switchboard, or on the front of the switchboard panel in the same manner as the TA Form A-2.

Line Drop Compensation

Line drop may be compensated for either by using a current transformer, as shown in Fig. 7, or by the method shown in the standard diagrams of these regulators. With this latter method there is a slight error due to changes of power factor, which is not of sufficient magnitude, however, to be of consesequence in ordinary installations.

Where greater accuracy is desired, a special line drop compensator is made for use with this regulator and is connected to the line as shown in Fig. 8. With this device a resistance and reactance are used which are provided with taps so brought out that an artificial line can be produced by means of dial switch levers, and the constants of the artificial line made equivalent to those of the main line. With this arrangement of line drop, there is no error in voltage due to changes of power factor. The effect of capacity on the line, as well as that of inductance and resistance is compensated for. for loads of varying power factor.

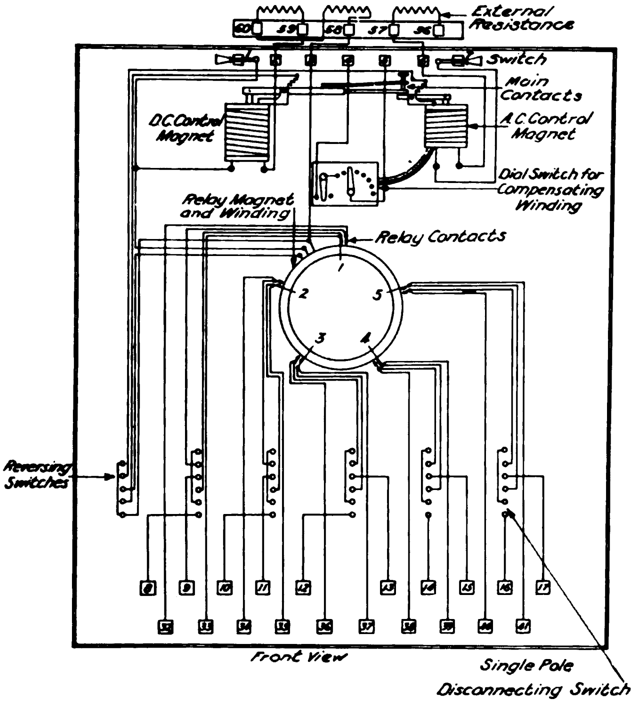

External Resistance
60
59
58
57
56
Switch
Main Contacts
D.C. Control Magnet
A.C. Control Magnet
Dial Switch for Compensating Winding
Relay Magnet and Winding
Relay Contacts
1
2
3
4
5
Reversing Switches
8
9
10
11
12
13
14
15
16
17
32
33
34
35
36
37
38
39
40
41
Front View
Single Pole Disconnecting Switch

Fig. 5. Internal Connections of the Type TA, Form F5 Regulator

Type TA Form K Regulators

The description of the type TA Form "F" regulator previously given also covers theoretically the description of the type TA Form K.

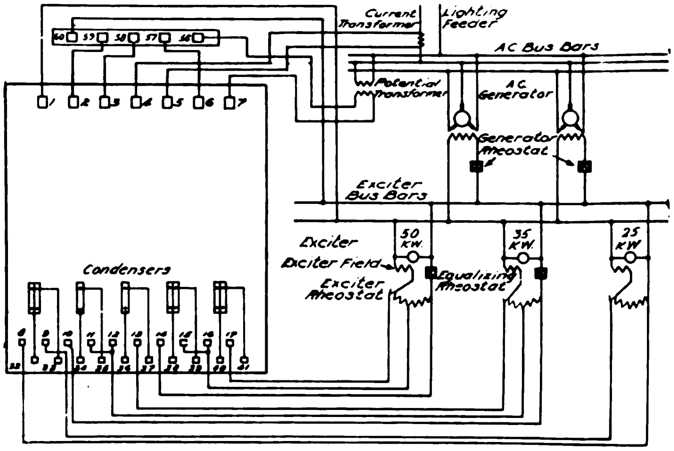

Current Transformer
Lighting Feeder
AC Bus Bars
60
59
58
57
56
1
2
3
4
5
6
7
Potential Transformer
A.C. Generator
Generator Rheostat
Exciter Bus Bars
Exciter
50 KW.
35 KW.
25 KW.
Exciter Field
Exciter Rheostat
Equalizing Rheostat
Condensers

Fig. 6. One Arrangement of External Connections of TA, Form F5 Regulator

The separate ratings of the Form K regulator, from K-14 to K-24, indicate the number of sets of relay contacts with which any particular regulator is designed. For instance, the type TA Form K-16 regulator, which we are about to describe at length in this article, is designed with 16 sets of relay contacts. These contacts are placed on two circular relay magnets, each carrying two sets of windings, which are wound with parallel conductors so as to neutralize the self-induction and reduce to a minimum the discharge at the main contacts. It will be noted that the main contacts actuate both sets of relay coils by cutting in and out one set of windings, the remaining set always being in circuit, so that when the main contacts are closed, the windings (which are differentially wound) will oppose one another and reduce the magnetism in the coils; thus allowing the armature supporting the relay contacts to close, due to the action of a spring connected to the armature. When the main contacts are open the spring is so calibrated that the power of the magnet overpowers it and the relay contacts are allowed to open. Inasmuch as the main contacts are floating on the line—due to a combination of magnet coils, springs and pivots—and are actuated by the potential of the a.c. bus on one coil and by the exciter bus on the other coil, their actual travel is very small, and for this reason they open and close at a high rate of vibration, which fact reduces the time element of the regulators to a minimum.

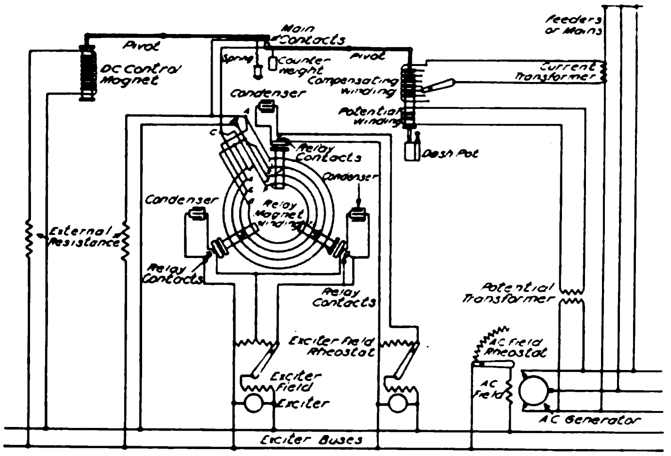

Main Contacts
Pivot
DC Control Magnet
Spring
Counter-weight
Pivot
Compensating Winding
Condenser
Potential Winding
Relay Contacts
Dash Pot
Condenser
Condenser
Relay Magnet Winding
External Resistance
Relay Contacts
Relay Contacts
Feeders or Mains
Current Transformer
Potential Transformer
Exciter Field Rheostat
Exciter Field
Exciter
AC Field Rheostat
AC Field
AC Generator
Exciter Buses

Fig. 7. Elementary Diagram of Type TA, Form F3 Regular Connections

The combined action of the above magnets, together with the adjustment of the exciter field rheostat, which is so adjusted that the exciter voltage will fall from 125 volts to 25 volts in from six to eight seconds, gives the regulator complete control over the excitation. When the exciter field rheostat is set for 25 volts, the alternating voltage will be in the neighborhood of 40 volts, assuming that the secondary voltage is 110 volts. If the regulator is then cut into service, the alternating voltage will build up to 110 volts—assuming that no-load conditions exist—and the exciter voltage will be in the neighborhood of about 70 volts. As the load gradually increases the regulator will automatically increase the excitation of the generator until the exciter voltage varies anywhere between the no load value of 70 volts and the full load value, which may be in the neighborhood of 125 volts. By this combination there is absolutely no time element in the operation of the regulator itself; as the dashpot, which tends to retard the rapid opening and closing of the contacts, can be so adjusted that it will correspond to the time elements of the generator and exciter. If this dashpot is set too freely, the regulator will tend to hunt, due to its being quicker than the exciter and generator. By the adjustment of the dashpot this hunting can be readily overcome, and the operation, while not being impaired, can be made to agree with the characteristics of the machines which the regulator is to control.

From the first part of this article it will be noted that the K type of regulator is an enlargement of the F type, and the question may be asked as to why it is not feasible to continue to increase the number of magnets as the demand of the station increases. With the present method of operation and construction it has been found impractical to enlarge this type of regulator above the two sets of relay magnets, since not only would the discharge at the main contacts be such as to rapidly wear away the contacts, but the voltage would not be steady, due to the continual sparking.

The successful operation of the Form K regulator depends entirely upon its being installed in a satisfactory manner. In order to bring out more clearly the necessity of following instructions in this respect, I will

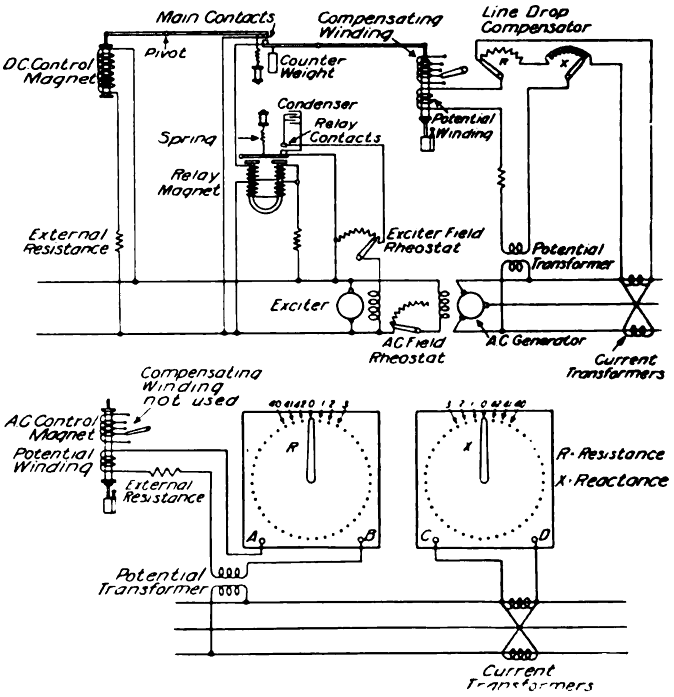

Main Contacts
Compensating Winding
Line Drop Compensator
DC Control Magnet
Pivot
Counter Weight
Condenser
Relay Contacts
Spring
Potential Winding
Relay Magnet
External Resistance
Exciter Field Rheostat
Potential Transformer
Exciter
AC Field Rheostat
AC Generator
Current Transformers
Compensating Winding not used
AC Control Magnet
Potential Winding
External Resistance
R
X
A
B
C
D
R-Resistance
X-Reactance
Potential Transformer
Current Transformers

Fig. 8. Connections of Regulators using Line Drop Compensator

outline the installation and the method of connections of a type TA Form K-16 regulator for the Rio Das Lages power house of the Rio Janeiro Tramways Light & Power Company. Fig. 9 shows the front view of the K-16 regulator in question and Fig. 10 the back view. The generating equipment of this plant consists of six 4000 kw., 6000 volt alternators, operating in parallel and excited from four 200 kw., 250 volt exciters, the latter machines being also operated in parallel. It will be noted from Fig. 11, which shows the external connections of the regulator, that the a.c. bus bars, as well as the exciter bus bars, are sectionalized, so that one half of the station can be entirely shut down, or run by hand regulation. A line drop compensator is used for compensating for line drop, the line being 51 miles long and operated at 44000 volts. The resistance drop is 16.2 per cent., and the reactance drop 24.8 per cent. The compensators are designed with 25 per cent. reactance and 25 per cent. resistance, and adjusted as previously described by dial switches on the compensators, which are adjusted for any percentage of resistance and reactance drop, up to the required limits.

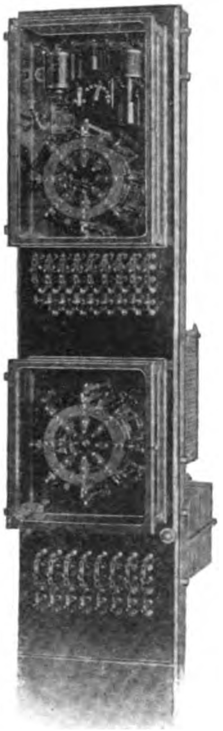


Fig. 9. Type TA Form K-16 Voltage Regulator Mounted on Standard Switchboard Panel

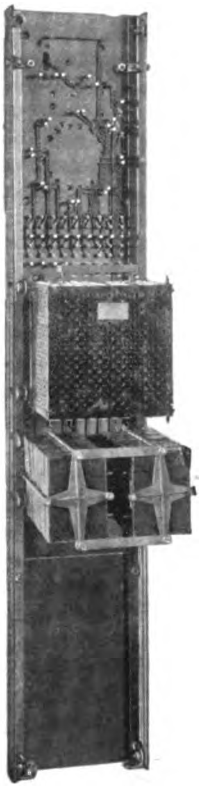


Fig. 10. Back View of Type TA Form K-16 Voltage Regulator

Referring to the connections of the Form K regulator to the four 200 kw. exciters, it will be noted that each exciter is provided with four relays. The rheostats are divided into four equal ohmic divisions, one set of relay contacts being placed across each section of the rheostat. Therefore it will be readily seen that the discharge across each set of relay contacts is exactly equal.

It frequently occurs that the connections of the Forms F and K regulators are made in such a manner that all the relay contacts are in multiple across the rheostat. A connection of this kind is improper, due to the fact that all the contacts may not open and close simultaneously; and consequently, if one set of contacts lags a little behind the others, this set will receive the full amount of the field discharge and will be rapidly destroyed. With the former arrangement it makes no difference whether one set of contacts is late in opening or not, as the discharge across these is proportional only to the resistance which each set is short circuiting. A simple method of determining the points for connecting the relay contacts to an exciter field rheostat, as shown in Fig. 11, is to first reduce the exciter voltage from 125 to 25 volts in from six to eight seconds, mark the rheostat switch, and leave it in this position. Then, by disconnecting the rheostat from its own exciter and connecting it to the remaining exciter, take the drop across the rheostat. Assuming that this drop is 80 volts and that it is necessary to tap the rheostat in four sections, the voltage drop across the buttons of the rheostat should be taken for the same value of current as before, and points determined which will divide the resistance into four sections, each giving a drop of 20 volts. A tap should then be brought out from each of these buttons and connected to the relay contacts; contact No. 1 being connected between the outside lead and tap No. 1; contact No. 2 between tap No. 1 and tap No. 2; contact No. 3 between tap No. 2 and tap No. 3; and contact No. 4 between tap No. 3 and the other outside lead. In Fig. 7 of the elementary diagram of the F-3 regulator, the exciter field rheostat is shown divided into two sections and the fact that the middle tap is common to both sets of relay contacts is readily seen.

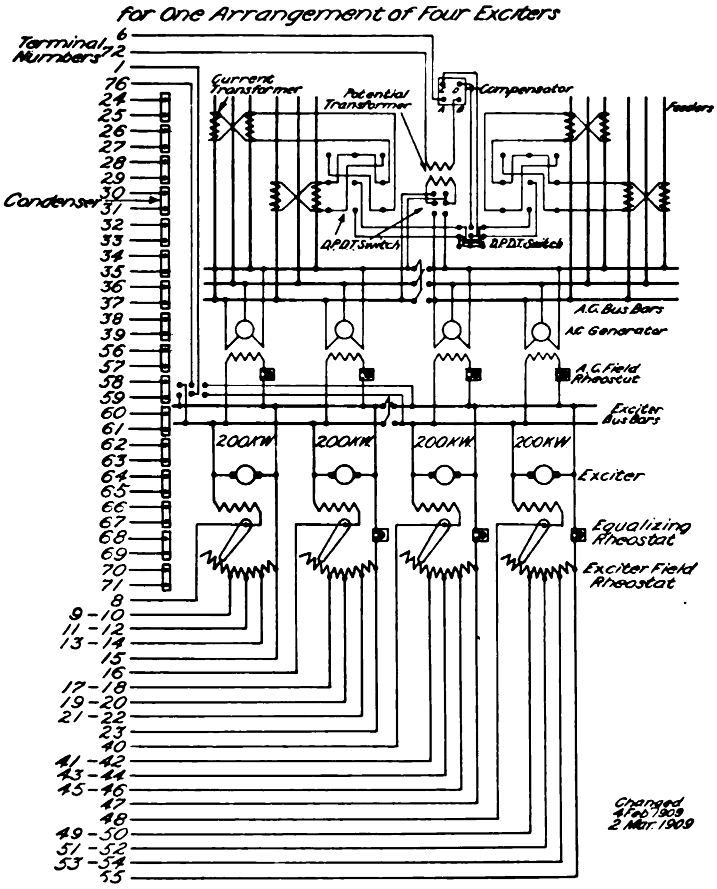

For One Arrangement of Four Exciters
Terminal Numbers
6
72
1
76
24
25
26
27
28
29
Condenser
30
31
32
33
34
35
36
37
38
39
56
57
58
59
60
61
62
63
64
65
66
67
68
69
70
71
8
9-10
11-12
13-14
15
16
17-18
19-20
21-22
23
40
41-42
43-44
45-46
47
48
49-50
51-52
53-54
55
Current Transformer
Potential Transformer
Compensator
Feeders
D.P.D.T. Switch
D.P.D.T. Switch
A.C. Bus Bars
A.C. Generator
A.C. Field Rheostat
Exciter Bus Bars
200KW
200KW
200KW
200KW
Exciter
Equalizing Rheostat
Exciter Field Rheostat
Changed 4 Feb 1909
2 Mar 1909

Fig. 11. Diagram of External Connections of Type TA Form K-16 Regulator Arranged for Controlling Six 4000 Kw. Alternators Receiving Excitation from Four 200 Kw. Exciters

These regulators can be mounted in a number of different ways. The K-16 regulator described above is shown mounted on a two section 16 in. panel. Another method of mounting these regulators is illustrated in Fig. 12, which shows the type TA Form K-20 regulator mounted on a cast iron pedestal. This method of mounting is very satisfactory, as the pedestal is designed with sufficient space in the base to allow of all wires connected to the regulator being brought up through it, and thus concealed from view. The external resistance of the regulator is also mounted inside the pedestal.

Where a station is crowded for room and it is desired to eliminate the necessity of running long wires from the exciters, it frequently occurs that the pedestal can be mounted in front of or near the exciter panels. In this position the regulator is not only more readily handled, but the paralleling of the exciters is much more easily effected than when the regulator is located at the opposite end of the board from the exciter panels.

The Form "K" regulator can be arranged to compensate for line drop, as can also other types of alternating current regulators. All regulators are supplied with the compensating winding, whether line drop compensator is desired or not. For compensation of purely non-inductive load it is only necessary to insert a current transformer in the principal lighting feeder. If it is desired to compensate for both inductive and resistance drop, the line drop compensator is used, as previously described, with the addition of two current transformers.

It is very necessary, in order to get satisfactory operation of all types of multiple relay regulators, to have the regulators of sufficient size to take care of all the exciters in the station, whether one exciter is used at a time or all. This avoids the complication of external switches and also avoids any possibility of interruption of voltage when paralleling the exciters and generators, and cutting in and out different exciters.

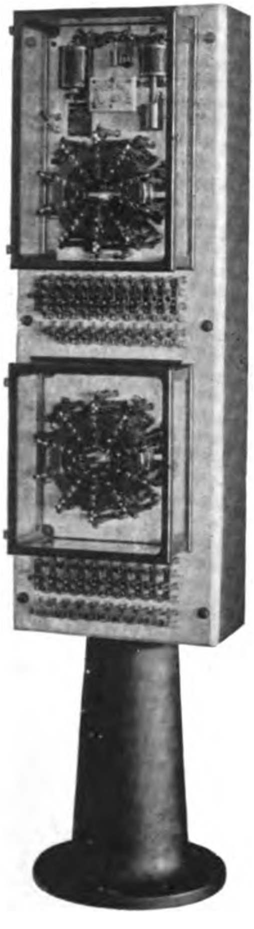


Fig. 12. Type TA Form K-20 Regulator Mounted on Pedestal

Regulators for special applications of alternating current work will be described in a later issue.

THE INTENSIFIED ENCLOSED ARC

By W. D'A. Ryan

For more than ten years the enclosed arc lamp has been greatly in favor for general mercantile lighting, in virtue of its whiteness, high efficiency and low maintenance cost.

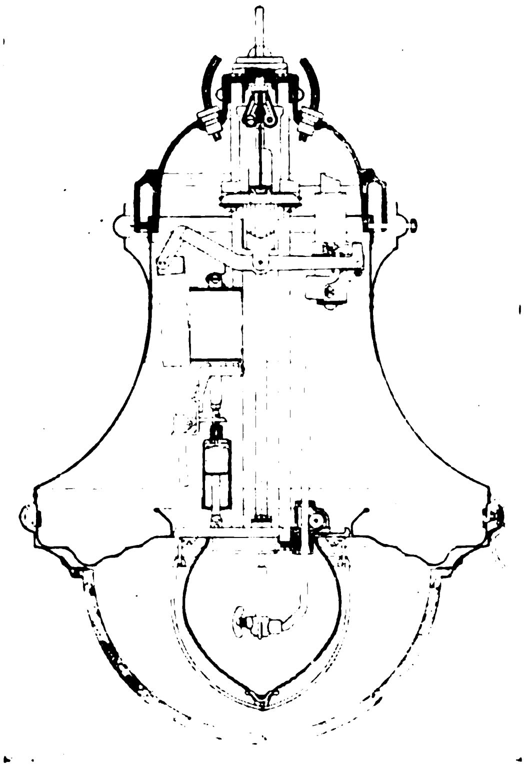
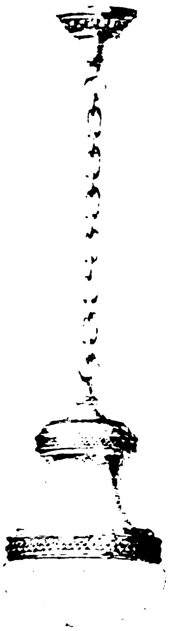


Fig. 1. Section through Intensified Arc Lamp

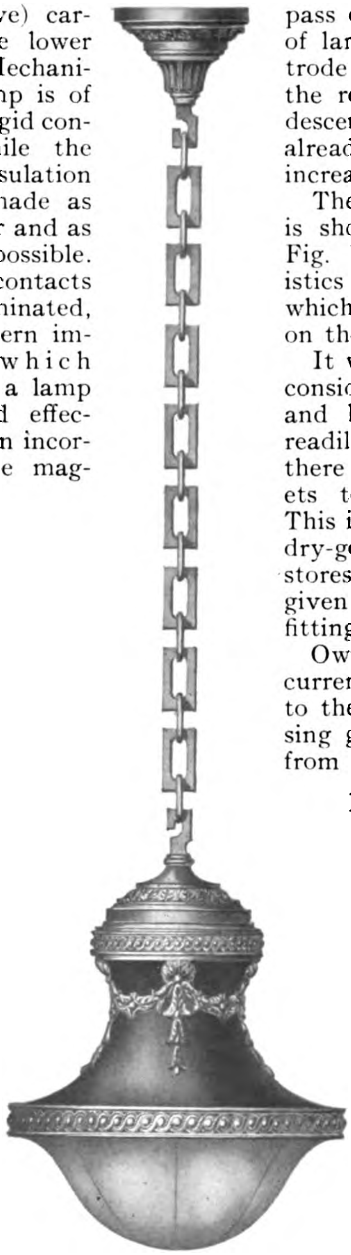
While it still holds first place on the basis of whiteness and minimum cost of up-keep, the tungsten lamp, which bids fair to revolutionize the entire lighting field, has surpassed it on the point of efficiency.

The necessity for improvement in the enclosed arc has been carefully considered by arc lamp engineers of the General Electric Company, with the result that development has rapidly progressed and they are now in a position to announce an improvement in the art quite in keeping with the advantages that the tungsten has gained over its predecessor, the carbon filament lamp.

While the intensified arc lamp is essentially of the enclosed arc type, it differs radically from the previous designs in the arrangement of carbons and in mechanical construction. The lamp is equipped with two small diameter upper (positive) carbons and one lower (negative). Mechanically the lamp is of remarkably rigid construction, while the points of insulation have been made as few in number and as durable as possible. All sliding contacts have been eliminated, and all modern improvements which tend to make a lamp reliable and effective have been incorporated. The magnets are wire wound with fireproof insulation.



Intensified Arc Lamp Greek Style Ornamentation



Intensified Arc Lamp, Empire Style Ornamentation

The lamp complete with outer globe weighs about 26½ lb., and has a length overall of 24 ins.

When adjusted for 5 amperes and equipped with two 12 in. by ¼ in. upper carbons and one 3½ in. by ⅝ in. lower carbon, the lamp will burn about 75 hours.

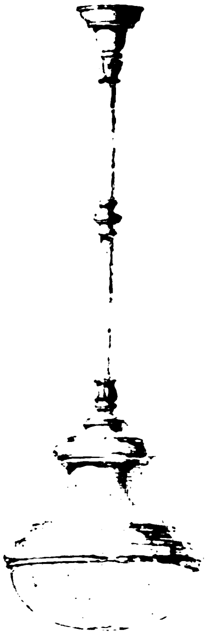
The gain in lighting efficiency is partly due to the arrangement of the arc itself and partly to the more efficient distribution. The light, which is usually distributed in the upper hemisphere by the ordinary enclosed arc, is efficiently diverted into the lower hemisphere by a suitable reflector, which is so designed as to expose but little diffusing surface to the ceiling, thereby raising the lower hemispherical efficiency.

The current density in the small carbons is relatively high, and as the heat cannot pass off by conduction, as in the case of large carbons, the end of the electrode passes from what might be called the red hot poker stage to the incandescent, thereby adding light to that already given by the crater; hence the increased efficiency.

The general construction of the lamp is shown in the accompanying cut, Fig. 1, and the distribution characteristics in Fig. 2. Some of the designs in which the lamp is made are illustrated on the opposite page.

It will be noted that the lamp differs considerably from conventional designs and has very pleasing lines. It can readily be cleaned with a duster as there are no heavy projections or pockets to act as accumulators of dust. This is quite essential, particularly for dry-goods, clothing and department stores, where unusual attention is being given to this feature in the case of all fittings and store equipment.

Owing to the high current density and to the use of a diffusing globe, the light from the Intensified Arc is whiter than that of the



Intensified Arc Lamp Flemish Style Ornamentation ordinary enclosed arc. The lower hemispherical efficiency is approximately 1 watt per candle initially, but this may be modified to meet various conditions to, say, 2 watts per candle.

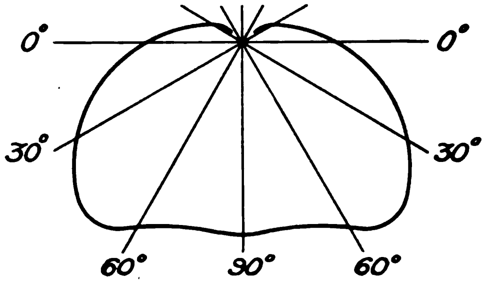


Fig. 2. Photometric Characteristic with Opal Art Glass Outer Globe

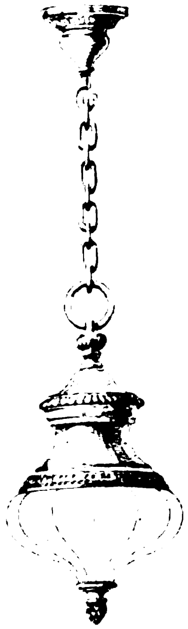
A very satisfactory globe to meet average store requirements is made of leaded light granite opal glass. This gives an illumination slightly warmer in color tone than average daylight, at an efficiency of approximately 1.5 watts per lower hemispherical candlepower. The light is well distributed and is not hard on the eyes.

The lamp illustrated herein is for use on a 110 volt direct current circuit and is wound for 5 or 6 amperes and adjusted for 80 volts at the arc.

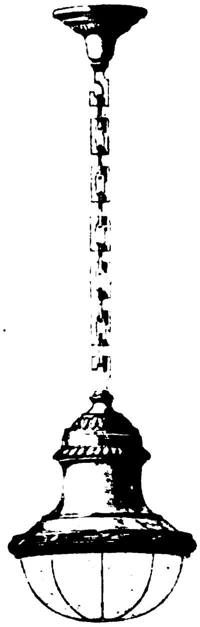
The approximate life for each of the currents mentioned is, respectively, 60 and 75 hours.

In addition to the plain casing, ornamental casings will be furnished in designs ranging in price from about $15.00 to $75.00 each.

Briefly, the intensified arc possesses the following advantages: high efficiency, economical and effective distribution, good color value, low maintenance cost, and artistic design.



Intensified Arc Lamp Norman Style Ornamentation



Intensified Arc Lamp Roman Style Ornamentation

CURVE FOR THE CALCULATION OF THE RELATIVE COSTS OF ALUMINUM AND COPPER

By M. W. Franklin

Power and Mining Engineering Department, General Electric Company

The question of the use of aluminum or of copper for transmission lines has virtually become a matter of cost alone. The methods of producing aluminum have been developed so far that perfectly satisfactory conductors are to be expected, and where a monetary saving is effected, the use of aluminum may be recommended.

The merits of aluminum as apposed to those of copper may be briefly summarized as follows:—

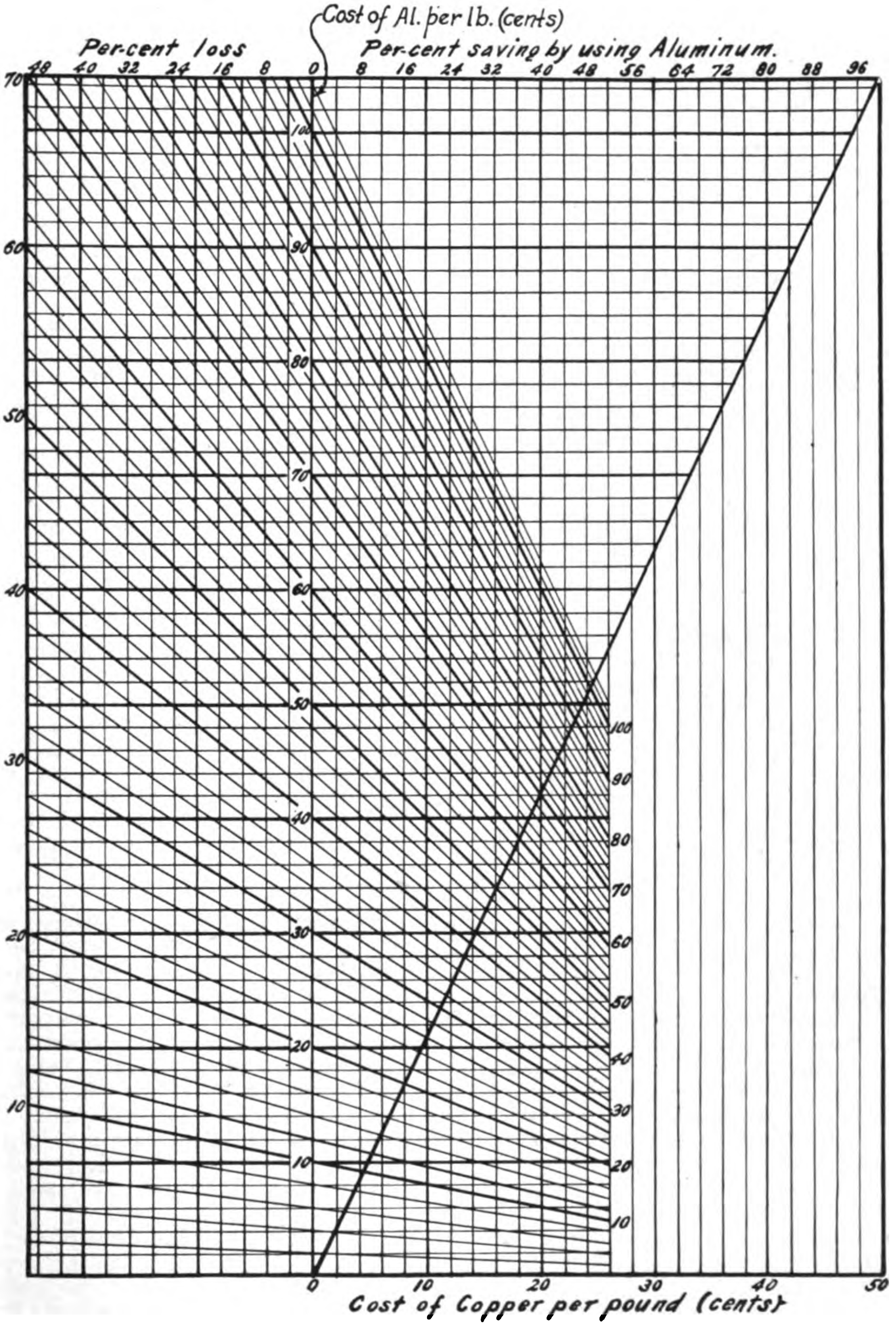
1. Aluminum conductors gather less sleet than do copper conductors.
2. Greater care in stringing must be exercised with aluminum to avoid abrasion and other injuries to the softer metal.
3. Aluminum costs less to string than copper, since it is lighter.
4. The weight of aluminum is about 51 per cent. less than that of copper; therefore the pole lines need not be so strong and expensive.
5. The greater expansion coefficient and elasticity of aluminum result in greater sags, and consequently the height of the towers will be greater than with copper.
6. The greater sag will necessitate greater interaxial spacing.
7. The lower melting point of aluminum increases the danger from arcing.
8. The greater radius of aluminum wire lessens leakage.
9. The greater surface increases wind stress.
10. The greater spacing increases line inductance.
11. Stranded aluminum conductors show no tendency to break.

The conductivity of aluminum is generally given as 63.3 per cent. that of hard drawn copper of the same cross-sectional area. The relative weight of aluminum is 30.20 per cent. that of hard drawn copper; therefore an aluminum conductor of a given length and conductivity will weigh 47.7 per cent. as much as an equivalent copper conductor. The cost of aluminum can therefore be about twice, or more accurately 2.097 times that of hard drawn copper and give a conductor of the same length and conductivity for the same cost.

In calculating the cost of aluminum as compared with that of copper, it is necessary to consider the specific gravities, conductivities and relative costs of the two metals. Since the conductivity of aluminum is 63.3 per cent that of copper, an aluminum conductor, to possess a conductivity equal to that of a given copper conductor, would of necessity have an area 1.58 times as great; but the specific gravity of aluminum being only 30.20 per cent. that of copper, the weight of the larger conductor would be only 47.7 per cent. that of the smaller copper one. From this it will be seen that the weight of a copper conductor will be 2.097 times that of an aluminum conductor of the same conductivity, and therefore 2.097 times as much must be paid per pound for aluminum as for copper to make the cost of the two conductors equal. If aluminum costs less or more than 2.097 times as much as copper, the difference per pound multiplied by the number of pounds of aluminum will give the total saving or loss effected. This total saving or loss divided by the cost of the copper conductor will represent the per cent. saving or loss resulting from using aluminum instead of copper.

For any given cost of copper the corresponding cost of aluminum necessary to give a line of equal cost can be determined at once from the accompanying curve, as can also the per cent. saving or loss. The curve is used as follows:

Suppose that the cost of copper is 16 cts. per pound; then on the lower scale of the curve find the vertical line corresponding to 16 cts. Where this line intersects the diagonal curve is found the horizontal line corresponding to the cost of aluminum. This cost will be found in the column marked "cost of aluminum per pound", which runs vertically up through the scale. This is seen to be 34 cts., which indicates that when copper is 16 cts. per pound, aluminum may be 34 cts. per pound and the cost of the line not increased through its use. But supposing that aluminum, instead of being 34 cts. per pound, is 32 cts.; follow the horizontal line through 32 cts. to the right to the point where it intersects the oblique line corresponding to 34 cts., and directly above this point of intersection on the upper scale is found 6, which is the per cent. saving effected by using aluminum instead of copper when copper is 16 cts. per pound and aluminum 32 cts.



THERMODYNAMICS

PART V

BY DR. CHARLES P. STEINMETZ

As indicated in the previous article, the late development of the steam turbine is partly due to the high velocity of the steam jet when expanding from one pressure to another. When the jet expands through the entire range from boiler pressure to condenser pressure, the velocity is 4000 ft. per second; when the expansion takes place in three successive steps, 3000 ft. per second; and when expanding in four steps, 2000 ft. per second. These velocities are considerably greater than can be employed directly by machinery.

The spouting velocity of water at the highest heads available, namely 2,000 feet, only amounts to 360 feet per second. This velocity in an impulse turbine wheel would require a peripheral speed of 180 feet per second, which speed is well within the range of high speed machinery. To use velocities of 4000 feet per second, a steam turbine wheel would have to run with a speed of 2,000 feet per second; a speed which is entirely out of the question.

Imagine a jet of some fluid, water or steam, escaping from a nozzle at a speed s_0 and striking a turbine blade which is at rest: it will rebound at the same velocity at which it struck the blade, the return jet not mixing with the incoming jet. If the blade moves with speed s, the relative speed with which the water or steam strikes is $s_0 - s$. On rebounding from the moving blade the jet has lost in velocity. This loss equals twice the velocity of the moving wheel, since the jet leaves the blade at the same relative velocity at which it enters. The relative inlet velocity is $s_0 - s$, hence the velocity of escape is $s_0 - 2s$.

Impulse Turbine

Consider the type of turbine in which the nozzle is at rest and the blade moves: then as one blade leaves the path of the jet another blade enters it and so on in rotation, the blades being so situated in respect to the direction of the jet that a continuous motion is imparted to each blade successively. Maximum efficiency is obtained when $2s = s_0$, because the relative velocity of escape is then zero, and the jet has imparted all its available energy to the blades. If the resistance to motion is very small, the blades will move faster and faster until they move approximately as fast as the velocity of the jet which strikes them. In this case practically no energy is transmitted, and the free running speed will be $s = s_0$. This type of turbine is the impulse or impact turbine, so called because it revolves due to the impact of the jet upon the moving blades. Its characteristics are that maximum efficiency and output obtain when the wheel velocity is equal to ½ the jet velocity, the free running speed being equal to the jet velocity.

Reaction Turbine

If the jet spouts with velocity s_0 from a moving nozzle the reaction on the nozzle causes it to move backwards with velocity s. The absolute velocity of the jet is $s_0 - s$, and if the total velocity of the jet is imparted to the nozzle the absolute velocity will be zero; that is to say the jet will drop straight down on leaving the nozzle. In such a case maximum efficiency is obtained and $s = s_0$. If the wheel runs without resistance its speed will increase, and it will finally move so that the reaction between the jet and the wheel is zero. This occurs when the speed of the wheel backwards is twice the absolute velocity of the jet, in which case the jet issues from the wheel with a relative velocity equal to its absolute velocity.

Thus there are two types of turbines—impulse and reaction. In the impulse turbine the speed of the rotor equals ½ the jet speed; in the reaction type the rotor speed equals the jet speed, for maximum efficiencies. The reaction turbine is not used for power work and is only employed in very small apparatus, such as revolving garden sprinklers.

Wheel Speeds

Though the impulse turbine requires only ½ the speed of the reaction turbine for the same jet velocity, the necessary speed is still too high for practical operation if all the energy of the steam between boiler and condenser pressure is imparted to one wheel. One method of reducing the wheel speed is to break up the pressure range into several steps. For instance, suppose that four successive expansions or steps are used; from boiler pressure to the first intermediate pressure, then to a lower pressure, and so on till finally to the condenser pressure. In each of these expansions one quarter of the total energy is used, therefore the square of the velocity lost is one quarter of the square of the total velocity. The energy per expansion decreases with the number of expansions, and therefore velocity squared also decreases with the number of expansions. With n expansions the velocity is reduced by $\frac{1}{\sqrt{n}}$ per expansion. To reduce the velocity to one quarter will therefore require 16 steps or stages. In the reaction type of turbines, for the same rotor velocity, *viz.*, 500 feet per second, the velocity of the jet would have to be reduced to one eighth in order to utilize the total pressure range; hence 64 successive expansions would be necessary.

Every impulse turbine in which the jet passes through two successive wheels, requires a wheel velocity equal to one fourth of the jet velocity. Each revolving wheel takes twice its velocity out of the jet. With m successive wheels the outflow velocity from the last wheel is $s_0 - 2m$ times the wheel velocity. By passing the jet through four successive wheels, it is possible, theoretically, to take out of the steam jet all the energy that it possesses when expanding from boiler to condenser pressure; each wheel taking out twice its own velocity from the velocity of the jet. This is not feasible, however, because the steam jet disintegrates when turning around over the wheels: it does not keep to one path but scatters and loses efficiency: the impact is not direct but fractional and in various directions. Hence, when a number of wheels are used in succession, the efficiency decreases rapidly, and it is not practical to use more than two, or at the most three, velocity steps in series. If the stages were pressure steps, sixteen would be required instead of the four velocity steps. 16 pressure steps would make the turbine complicated, and four successive wheels would make it inefficient; thus a combination is necessary, and a number of pressure steps, each using several wheels, should be employed.

If the elementary form of structure already outlined is used, successive wheels will move in opposite directions, which fact is a serious disadvantage and such a type has not yet been developed. To overcome this difficulty intermediate or stationary blades are provided between the moving blades; their function being to turn the jet around after passing through the first set of moving blades, so that it strikes the second wheel in a similar manner to the first. In other words the direction of the motion of the jet is changed between each moving wheel by means of the intermediates. By this construction several pressure stages can be used, in each of which two or three wheels move and abstract velocity; that is, two or three velocity steps or wheels are contained in each stage or expansion step, there being a boundary wall between successive stages which is perforated by the steam nozzles which convert the pressure of the steam into kinetic energy by expansion.

In the Curtis turbine, velocity steps are combined with expansion steps. If two wheels are used per stage, each wheel revolving at the rate of 500 feet per second, the stage can take care of a steam velocity of 1,000 feet per second and two successive stages of two wheels can each utilize a steam velocity of 2,000 feet per second. If the total velocity of the steam is 4000 feet per second, four successive stages are required, each consisting of two wheels, eight wheels being required altogether.

Characteristics of Expansion Turbine

In the combination turbine (Parsons' type), expansion takes place in each wheel, stationary as well as revolving. As the pressure varies across the wheels, an end thrust is produced, and only small clearances are possible between successive wheels in order to minimize steam leakage; there is a pressure difference across the wheel. All the nozzles must operate simultaneously on the wheels, otherwise steam or water will flow back; thus this type of turbine operates most efficiently at full load. Small loads cannot be governed by closing some of the steam passages, they must all be open. Governing can only be effected by shutting off steam, hence a reduction of load is obtained by alternately admitting and shutting off steam, which operation means a continuous starting and stopping with a resulting loss of efficiency. When the nozzles are all partly closed a back flow of steam results and a leakage of steam occurs. The same kind of difficulty is experienced with turbine blowers or compressors. If the load decreases the pressure is lost—not enough air passes through the blower to hold the pressure back—and a return flow of air occurs. At the same time, this type of turbine holds an advantage in that the relative velocity is small: the steam velocity relative to each wheel is zero at its entrance and equals the wheel velocity at its exit; whereas in the impulse type, the relative velocity of entrance is three times the wheel velocity, which is equal to the relative velocity of the steam at exit.

Steam Friction

For this reason the steam friction losses are lower in the combination turbine. It has, however, higher wheel friction because a greater number of wheels are used. When you are dealing with velocities as high as 450 feet per second, the friction losses become very large. This is readily realized when the velocity of a gale of wind is considered. In this case the air moves with a velocity of 100 miles an hour, that is, 147 feet per second, which velocity is only one half or one third as great as that of the steam when it leaves the last wheel. Even with a steam speed of only 250 feet per second, the friction losses at the rotating wheel are considerable. The friction per unit area varies as the square of of the velocity. In a wheel of diameter d, the total friction is equal to that per unit area multiplied by the total area; in the case of discs the area varies as the square of the diameter, and therefore the friction of the turbine discs against the steam is proportional to the square of the disc diameter and the square of the steam velocity conjointly. Consequently the power consumed is proportional to d^2s^3 for the disc, and hds^3 for the rim; where h is the height of the rim, d the diameter of the disc, and s the relative steam velocity. These calculations are essentially the same for the reaction and the impulse turbine. The efficiency of the rotating wheels of turbines varies with the size of the openings, the speed of revolution, the relative steam velocity, and other factors, and lies between 60 and 85 per cent.

Moisture and Re-evaporation

As the steam expands from one pressure to another its energy is converted into the energy of velocity. The steam is dry when it enters the nozzle, but on leaving it contains some moisture. It then passes through the turbine wheels where its velocity is converted into mechanical motion. That portion of the energy lost by the steam due to friction through the wheel is converted into heat, which evaporates the moisture contained in the steam. If adiabatic expansion occurs 6 per cent. moisture is produced. The efficiency of the conversion of the energy of the steam velocity into the energy of mechanical rotation, can be taken as 70 per cent; that is to say, 30 per cent. of the energy available for mechanical work is lost; this is converted into heat and remains in the steam. Since the pressure of the steam is constant, the temperature corresponds to the boiling point at that pressure; and the heat energy which is produced by the loss of energy due to friction re-evaporates part of the condensed moisture, the amount of which can be calculated if the energy of expansion is known. Hence all the loss due to steam friction is converted into heat, which decreases the amount of moisture present in the steam.

If the energy were equally divided between the four stages of a turbine, the arrangement would not, however, give an equal distribution of energy to the wheels in each stage. If no energy losses occur, three quarters of the energy is available for use in the three last stages; but in the first stage only 70 per cent. of the energy of steam velocity is absorbed by the wheel, the remaining 30 per cent. is lost by friction and converted into heat, which is contained in the steam on leaving the first stage. Hence the loss of energy in each stage is available for each successive stage. Thus, in order to obtain equal mechanical energy on the wheels in all four stages, the wheels, blades, etc., should be so proportioned that somewhat more than one quarter of the total available energy is abstracted from the steam velocity in the first stage.

Superheated Steam

If the specific heat of steam is known, and taken as 0.525, then the energy required to heat one kilogramme of steam one degree equals 0.525 multiplied by 426 calories, or about 220 kgm. The condensation of one kilogramme of steam produces the same amount of heat as would be required to raise the steam 1000 degrees C.; hence the condensation of 1 per cent. of the steam liberates as much heat as would raise the whole of the steam 10 degrees C. In other words, 10 degrees superheat can be regarded as the negative equivalent of 1 per cent. of moisture in the steam evaporated; for this reason superheat can be reckoned as negative moisture. If steam is superheated it will become saturated by expansion, and moisture will be produced by further expansion.

For moderate amounts of superheat the steam equations can be used with approximately no change. This applies to superheat of 50 degrees C. or lower, in which cases the total amount of energy represented by the superheat is not very large and the equations may therefore be applied. When very highly superheated steam is under consideration, accurate results cannot be obtained from the equations relating to saturated steam; because the adiabatic constant and curve are different.

These constants, and the amount by which they change when passing from a state of superheated steam to saturated steam, have been given in the previous article, in which the energy equations will also be found.

STEEL WHEELS ON MINING LOCOMOTIVES

By R. V. Devlin

Power and Mining Engineering Department, General Electric Company

Within the past three years there has been a noticeable increase in the demand for steel tired and rolled steel wheels on mining locomotives. Formerly, all mine locomotives were equipped with the ordinary cast iron wheel which has a chilled tread and flange, the chill extending about ¾ in. below the surface. The use of steel wheels in steam railroad practice is, of course, no new thing, but the considerations leading to its adoption in that class of service do not hold in all cases for mine work. The one important consideration with steam roads, particularly in passenger service, is the matter of safety; the chances of wheel failures due to cracked treads and broken flanges and the resulting liability of derailment being reduced to a minimum with steel tires. In mine work, however, this has no important bearing, since speeds are low and if derailment occurs it is of no serious consequence.

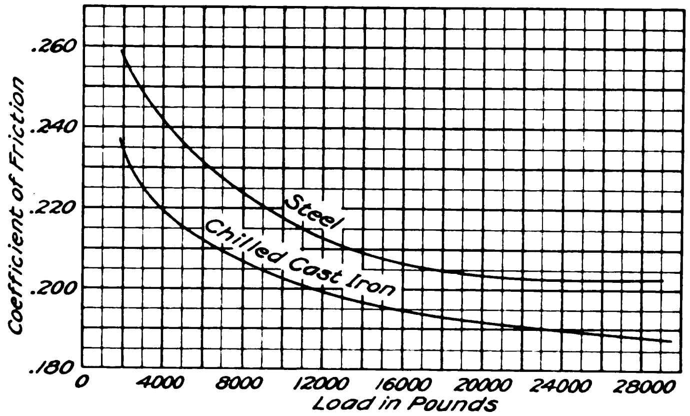


Fig. 1

Increased adhesion and economy are therefore about the only considerations that influence the adoption of steel wheels for mine service. Various claims are made regarding the adhesive qualities of the steel wheel and there appears to be a rather wide diversity of opinion among mine operators. Some have claimed that by replacing the cast iron wheels with steel tired ones an increase of 20 to 30 per cent. in the hauling capacity of a locomotive has been obtained. It is difficult, however, to make an accurate statement concerning the exact amount of increase since the coefficient of friction between wheel tread and rail is subject to wide variations, these variations being controlled by variable factors such as condition of rail, whether wet or dry; character of wheel tread, whether smooth or pitted; the amount and quality of sand used, etc.

A considerable portion of the increased tractive effort obtained when cast iron wheels are replaced by steel tired or rolled steel wheels, is due to the greater weight of the latter. In the sizes used on mining locomotives, steel wheels as at present furnished by the various manufacturers are very much heavier than the cast iron ones. In a particular case that came to the writer's attention, a 6-ton locomotive having four cast iron wheels weighing 400 lbs. each was later equipped with steel tired wheels weighing 650 lbs. each. This change brought the weight of the locomotive up to 13000 lbs., and assuming a coefficient of friction of 0.25, the maximum tractive effort was raised 250 lbs. (over 8 per cent.) due solely to the increased weight. Obviously, this increase in tractive effort could have been obtained with the chilled iron wheels by simply loading the locomotive frame with an equivalent dead weight.

In Fig. 1 is plotted the results of an exhaustive series of tests conducted in 1907 by Mr. Geo. L. Fowler for the Schoen Steel Wheel Co. These tests were made on a laboratory testing machine which was arranged to reproduce as closely as possible conditions existing in actual service. An inspection of these curves shows that the coefficient of friction of the steel wheel is from 4 to 10 per cent. greater than that of the chilled cast iron wheel, the coefficient varying with the load applied. A comparative test was made at the Schenectady works of the General Electric Co. several years ago on a 10-ton locomotive which was first equipped with a set of cast iron wheels and then with a set of steel tired wheels, sufficient dead weight being subtracted to compensate for the heavier wheels. The locomotive was placed on the test track and chained to a post, and current was supplied by a separately excited generator. A spring dynamometer was connected in the anchor chain and the current input to the motor increased gradually until the wheels slipped. These tests showed an average increase in the coefficient of friction of from 2 to 3 per cent. in favor of the steel wheels, although in a number of readings this coefficient was the same for the two materials, and, in one or two cases, lower for the steel wheels. It was impossible, however, to maintain constant conditions as regarded surface of rail head, etc., which fact may account for the discrepancies noticed.

In the matter of economy it is difficult to determine just what the saving is, and in some cases, if there is any saving at all. There is no question as to the longer life of the steel wheel, but there seems to be no data in existence that will enable an accurate comparison to be made on a basis of actual service conditions.

Mr. Fowler's investigations, previously referred to, included a series of abrasion tests on various types of steel tired, rolled steel, and cast chilled iron wheels. The test pieces consisted of cylinders ½ in. diameter which were cut from the center of the tread of each wheel. These test pieces were held against a carborundum wheel running at the rate of 2500 revolutions per minute, and the number of revolutions required to grind ⅛ in. from the test piece was recorded and used as a basis of comparison. From the results obtained it appeared that for the first ¼ in. of depth an average of about 15000 revolutions were required to grind off ⅛ in. of the steel wheel, and of the cast iron wheel, about 10000 revolutions. After the first ¼ in. was past, the steel wheel seemed to be harder, the number of revolutions per ⅛ in. wear running up in one case to about 50000. For the cast iron wheel, however, the rate of wear increased rapidly, and at a depth of about ⅜ in. from the surface the revolutions per ⅛ in. wear dropped to about 3000. These tests indicate that a new cast iron wheel will give almost as much service as the steel wheel, but that once the wear has penetrated ¼ in. below the surface, it is very much softer and wears away more rapidly; whereas with the steel wheel the metal seems to become harder below the surface and the wear is retarded considerably on this account.

The steel wheels, with their axle, can be taken out of the locomotive and the tread faced off when it has become worn too deep. This operation may be repeated several times, depending on the amount of wear. The chilled tread of the cast iron wheel, of course, does not permit its being turned, and when worn too deep for service the wheel must be scrapped. Cast iron wheels, however, are approximately 60 per cent. cheaper than steel tired wheels, and 45 per cent. cheaper than those of rolled steel. The higher cost of the steel wheels is offset largely by the fact that the treads may be refaced several times; but this saving is largely affected by the labor item involved in the removal and refacing. The cost of this operation will be determined by the repair shop equipment at the mine, or if there are no suitable tools available, the distance to which the wheels will have to be transported to reach a machine shop. It appears, therefore, that the matter of economy is determined by local conditions; that is, by the repair shop equipment of the mine and the character and cost of labor available.

RECENT DEVELOPMENTS IN TRANSFORMING APPARATUS

PART II

BY H. W. TOBEY

Recent Designs of Lighting Transformers

Turning now from some of the larger types of apparatus used more particularly in transmission and central station work, to some of the smaller transforming devices, it may be of interest to refer briefly, first, to lighting transformers. A great deal of attention has been given to this type in the way of reducing losses, improving the operation, and lowering the cost, without affecting durability and safety—more, perhaps, than to almost any other line.

Considering one particular size, the 5 kw. for example, it was usual ten years ago to find the core losses in the neighborhood of 90 watts or over. Improvements in material and design brought this core loss down to 80 watts, and still later to 70 watts when silicon iron was introduced. Then an entirely new form was designed and the losses were again reduced 10 or 12 per cent., bringing them to slightly more than 60 watts. During the past year still another improvement has been made in transformer iron, and by taking advantage of this and again modifying the designs, the core loss on the 5 kw. size was reduced to 45 watts. Thus, in ten years' time by a steady improvement in design and by using the best of material, the core loss has been reduced to half the original amount. During the same time the quality of the apparatus has steadily improved and the cost of manufacture has been lessened.

Small Lighting Transformer Removed from Case

There are several features of interest in the latest design of the type H transformer now being manufactured which it might be well to mention in passing. Perhaps the most noticeable is the symmetrical arrangement of coils and core, and the ingenious interlocking of the latter in the central leg. These features, together with correct proportioning of parts, has resulted in a relatively short mean length of iron and copper circuits; this is but another way of saying that the transformer contains a minimum amount of material for given losses.

Parts of Small Lighting Transformer

Another important feature of this design, but one not so evident at first sight, is the restricted area in the central core. This brings about two results: First, the shortening of the mean length of turn in the copper circuits; second, an increase in the flux density in the central leg of the magnetic circuit. Such an increase in density results, to be sure, in higher losses in this part of the core, but they occur in only a comparatively small part, and are more than offset by low losses in the four external magnetic circuits, where the area of cross section can be made large without in any way interfering with the space occupied by the winding.

Tungsten Lamp Compensator

In the first part of the paper mention was made of some of the larger sizes of transformers. We will refer now to one of the smallest types built—that known as the tungsten lamp compensator.

This device was developed to accommodate low voltage tungsten lamps to standard circuits, usually reducing the latter voltage in the ratio of about 4 to 1. It is so arranged that it can be inserted in an ordinary lamp socket.

It is of interest not only because of its small dimensions but also on account of its somewhat unusual efficiency characteristics.

Compensator for Tungsten Lamp

Fortunately, in the device we are considering, not only is the capacity small—25 watts—but the voltage requirements are low, and it has therefore been possible by careful design and correct proportioning of material to obtain an efficiency of over 85 per cent. What is perhaps of equal interest is that this efficiency is maintained for voltages ranging from 110 to 130 and for loads ranging from full to less than half.

Where we have the ordinary line voltage of 2200 or 2300 to contend with, the amount of active material, made necessary by the space required for insulation, is comparatively large. This has led to the impression that small transformers must necessarily have low efficiencies, so that in the case of one of 25 watts capacity, for example, 60 or 70 per cent. at full load would not be thought unreasonable, this falling to perhaps 40 or 50 per cent. at half load.

By comparing these values with those mentioned a moment ago, it will be seen that if the conditions are favorable the efficiency of even small transformers can be comparatively high.

Hardening and Annealing Furnace

An outline of recent developments in transforming devices would hardly be complete without mention of the electric furnace. This is too broad a subject to fully consider here, so only one type will be touched upon and this very briefly—the electric annealing and tempering furnace.

For many years, as we all know, it has been customary, in the process of annealing and tempering, to resort to coal or gas heated furnaces, the metal to be treated being exposed either directly to the flame or packed in some heat conducting material.

These methods all have their disadvantages, however, one of the most serious being the difficulty experienced in raising the temperature uniformly to the desired value, and then maintaining it for the required length of time.

The lead bath and the cyanide process, too, both have their limitations and disadvantages.

The electric annealing and hardening furnace, which has been developed during the past few months has, on the other hand, many valuable features which are not present in the devices just mentioned. Its bath is composed either of pure barium chloride, a mixture of the chlorides of barium and potassium, or, in some cases, a mixture of potassium chloride and sodium nitrate, depending on the temperature at which it is desired to operate. By selecting the proper mixture then, and adjusting the current which flows directly through the bath, any temperature from 200° Cent. to more than 1300° Cent. can be obtained and held at a perfectly uniform value. These features, together with the fact that the bath used does not in any way affect the composition of material which is to be treated, makes the device exceedingly useful and valuable

The electrical part of the equipment consists of a transformer and regulator connected to a suitable dial switch. By means of this arrangement, the voltage may be varied by small amounts over a wide range, thus making it possible to obtain any current desired.

Transformer Testing Equipment of the General Electric Company

The questions of testing and testing equipment became extremely important with the centralization of practically all of the transformer manufacture, and therefore it was only after a great deal of thought and study that the present layout was decided upon. This study included a review of the apparatus tested in the past and that likely to be tested in the future, together with an examination of the equipments in existence in the various testing departments.

The first requisite laid down was absolute safety to life; the second, safety to property; while the third and fourth were accuracy and the providing of an equipment which would enable the maximum amount of work to be turned out with minimum time and labor.

The equipment as now installed is entirely non-combustible. The floors are of concrete, the framework of piping and angle iron, and the switchboard of slate and marble.

All voltages above 500 are considered dangerous and are treated accordingly, by protecting them and keeping them out of reach. In general, the wiring is either on the back of the switchboard and entirely protected by screens or is in conduits underneath the floor. Machine frames, transformer cases, switch boxes, etc., together with the secondaries of the current and potential transformers are grounded; and, by means of metal strips running along the floor, the tanks or cases of all apparatus which is under test are likewise connected to earth. Practically all switches except those for low voltage circuits are of the oil type and are placed back of the board so as to still further reduce danger.

The individual testing boards and tables are arranged as closely as possible to the work in hand, so as to make possible the use of short cables leading up from the transformers to the proper line terminals, and thus reduce temporary connections to a minimum. This simplification and reduction of temporary wiring, perhaps as much as any other feature, serves to lessen danger to life and to facilitate the testing.

To reduce the fire risk and at the same time to facilitate the making of connections, etc., a pit 7 ft. deep, from 14 to 20 ft. wide, and over 130 ft. long has been installed, in which are placed all oil filled transformers while in test. This pit is provided at one end with a 30 in. drain pipe leading to the river, so that in case of fire the oil can be readily disposed of. As a still further safeguard, a 2 in. pipe connected with the live steam supply has been arranged for. This will make it possible to smother a fire by steam, should oil at the bottom of the pit become ignited. All oil for testing is stored underground and entirely away from the main building. When it is considered that the testing equipment is located in the midst of a floor area of over nine acres, 60 per cent. of which is covered by one roof, the importance of these precautions cannot be overestimated. Every switchboard and every generator is provided with a pilot lamp so that the operator can see its condition at a glance.

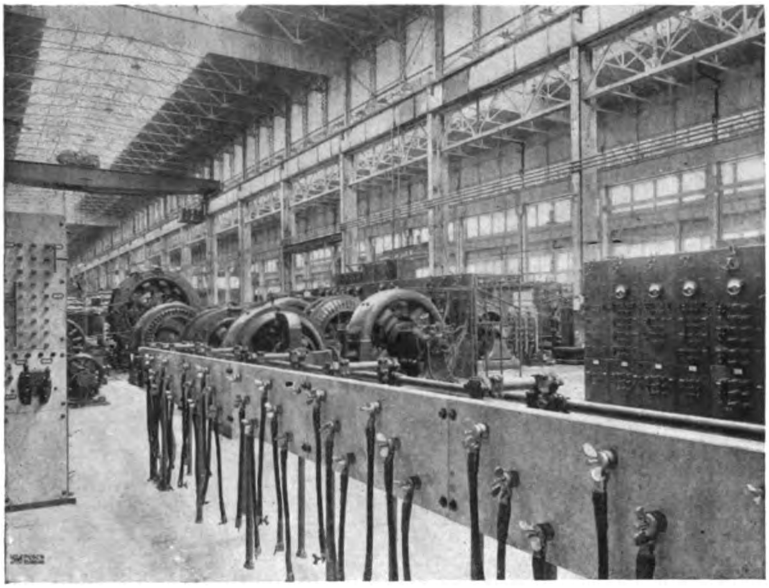
The majority of the generators and the testing transformers have their windings arranged in eight sections so that they may be grouped all in series, all in parallel, or in series parallel. This construction, together with regulating windings and field control, makes it possible to obtain any desired voltage at a moment's notice. The eight section arrangement is carried out also in the three-phase apparatus as well as in the single-phase; *i.e.*, each phase is divided into eight equal parts, so that star, delta or independent phase connections can be made over a very wide range of voltage. The ammeters for these machines, instead of being inserted in the outside circuit, as is customary, are connected into one winding only, so that regardless of the arrangement of connections, the instrument indicates at all times the proportionate load being carried. This largely eliminates danger of overloading due to the numerous forms of connections which are continuously possible.

The fields of all generators and motors in the test, both alternating current and direct current, are designed for excitation at 125 volts, and have a resistance such that the controlling rheostats may be entirely cut out and machines operated in this condition without overheating.

Each direct current generator is provided not only with an ordinary circuit breaker and no-voltage release, but also with a speed limiting device which automatically cuts the machine out if the speed exceeds a certain predetermined value.

The ratio transformers are all made for 25 cycles and therefore cannot be burned out at low frequencies—an accident which has occurred more than once when those of 60 cycle design were available.

In addition to the precautionary measures mentioned, many of the switches connecting instruments, transformers, etc., are provided with interlocking devices, making it practically impossible to obtain connections which would result in danger either to the operator or to the apparatus.



Section of Transformer Testing Department of General Electric Co.

One operation during the testing of transformers, particularly when they are of large size, and one which has always required a large amount of time and expense, is the heat run. Even when this is hastened by an overload, as has usually been customary, a number of hours elapse before the cold oil is brought up to even normal operating temperature, and moreover, all heat must be supplied electrically. These two drawbacks have been overcome in the new equipment by heating the oil by steam before it is forced into the transformers. The oil as it comes from the heater is stored in a large tank where it can be drawn off as required, and on the completion of the heat run the oil from the various pieces of apparatus is again pumped back into this tank, so that its temperature can be maintained at a comparatively small cost.

Another saving has been introduced in connection with the use of water for cooling water cooled transformers. One of the conditions of test is that this incoming water shall be maintained at a uniform temperature of 15° Cent., which means that during winter weather every gallon used must be raised at least 10° Cent. This has ordinarily been accomplished by passing it through some type of heater, allowing it to escape into a drain after accomplishing its purpose.

In the new equipment, the water discharged from each transformer is led back to the receiving tank and mixed with the cold incoming water in such proportions as to maintain a temperature of 15 degrees, thus saving the expense just mentioned. Thermostats and controlling devices automatically maintain this uniform temperature.

To eliminate the effect of low power factors on the main generating plant and to add to the flexibility of the testing equipment, the two-phase 60 cycle power, as originally generated, is not taken from the incoming lines until it has passed through motor-generator sets, these sets being installed on the floor of the testing room. By suitable excitation, then, the power factor of the generating station is maintained at a remarkably high value, usually about 97 per cent., while the power factor of the testing load varies between 10 and 40 per cent., averaging not over 25 per cent.

The various individual testing boards are provided with similar sets of current and potential transformers, voltmeters, ammeters and wattmeters, all of which are connected to special switches by permanent wiring. These arrangements are so complete that the man in charge of the test, by merely throwing certain switches, can measure any loss or load from 37 volts to 15,000, and from ½ to 500 amperes, at power factors ranging from 10 to 100 per cent., while frequencies of 25, 30, 40, 50, 60 and 80 can be obtained at a moment's notice.

All things considered, the equipment in point of safety to life, efficiency of operation, and general arrangement, is, so far as I know, the most complete of its kind in existence.

SOLENOID BRAKES FOR A.C. CRANE, HOIST, AND MILL MOTORS

By Edgar Price

Power and Mining Engineering Department, General Electric Company

Nearly all crane, hoist, and similar machinery require that the motors be stopped more or less quickly and frequently. To accomplish this a brake of some description must be used. All forms of braking—except that which uses the generator, or back torque action of the driving motor—are dependent on friction set up between specially constructed moving and stationary parts. The design of the brake parts for friction brakes depends upon the conditions to be met as well as upon the ideas of the designer.

The three most common types are, briefly, as follows:

1. A steel band is used, with wood friction blocks extending around a brake wheel. This is known as a "band brake."
2. Two rigid supports, hinged at one end and extending vertically on each side of the brake wheel, carry two brake shoes, one on each side of the brake wheel. This arrangement is called a "post brake."
3. One or a number of discs attached to the motor shaft are caused to rotate against similar stationary discs. Such a device is known as a "disc brake."

There are a great many modifications as to details of the above types. The post and band types are the ones which we use on A.C. motors. There are a number of methods of operating friction brakes depending, mainly, upon the amount of energy to be dissipated and the allowable time and frequency of the braking period. The means available are solenoids, air cylinders, and hand or foot levers.

There is an increasing tendency to make the operation of all classes of hoist and similar machinery more automatic, which fact means that hand and foot levers are being used much less than formerly. This means further, that electric and pneumatic operation of friction brakes is increasing.

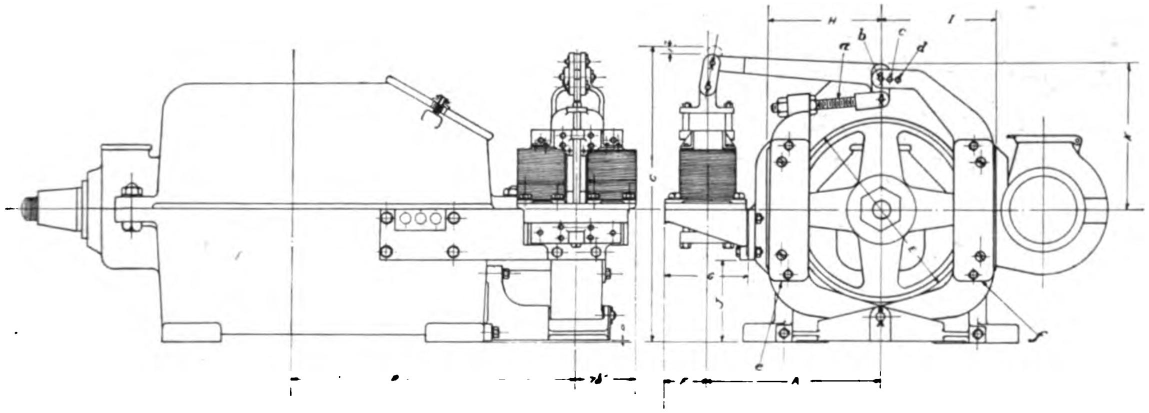


Fig. 1. Post Type Solenoid Brake as Applied to MI and MD Motors

Our purpose in this article is to refer only to solenoid operated friction brakes. In designing the mechanical parts of the friction brake for A.C. solenoid operation, it is of prime importance that the design be such as to require the minimum movement of the solenoid core. This reduces to a minimum the amount of power taken by the solenoid. The post type of brake best fulfills this requirement because all parts are rigid, and with pins and connections having reamed fits, there is the least possible lost motion at the solenoid.

The General Electric Company has a complete line of post type brakes for MI and MD motors. Those for the MI-105, to and including MI-109, are shown in Fig. 1. The same brake, except of course solenoid, is used on both MI and MD motors of the same size.

The standard brake shoes are made of wood with ample wearing surface, but metal shoes can be used if special conditions require or the customer prefers them.

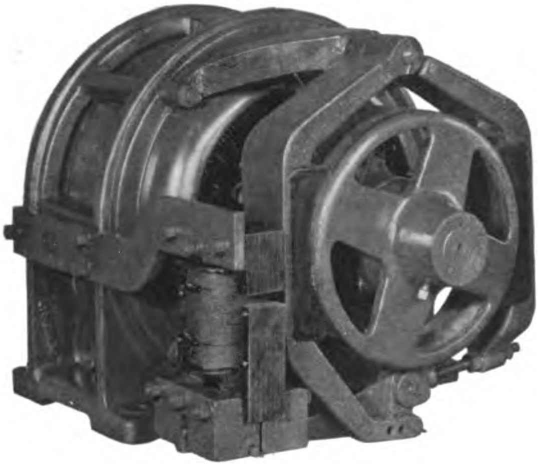


Fig. 2. Showing Brake Applied to ITC Motor

Attention should be called to the method of removing brake shoes and making adjustment for their wear. After the brake shoes have worn, thus lengthening the air gap of the solenoid and causing its operation to become sluggish—the rod "a" Fig. 1, is shortened by means of a nut on the end of rod outside of the brake yoke. This raises the movable core of the solenoid, thus shortening the air gap. This adjustment, it can readily be seen, requires the minimum of time and tools, it being a matter of a few minutes with a wrench. After the brakes have been subjected to several periods of wear, and corresponding adjustments have been made as just described, it will be found that the point "b" has moved about ¾ of an inch to the left; due to the wear of the brake shoe on the right hand side of the brake wheel. The hole "c" will then be about on the vertical center line, and the top pin and lever should be moved back to this hole, thus restoring the original effective length of lever. Later the hole "d" will be used, the limit on this hole being reached when the two shoes are completely worn out.

The brake shoes, Fig. 1, are attached to the plates "e" "f", which are fastened by means of tap bolts to the brake yokes. In removing the shoe for renewal, it is, therefore, only necessary to remove these tap bolts, and the shoes can then be pulled out without disassembling the brake.

All brakes for MI and MD motors, size 105 and up, have double coil solenoids assembled on a cast base, which is supported from the motor by means of a steel bar bolted to the lower half of motor; all brake parts are carried by a malleable iron bracket bolted to the bottom half of motor below the brake wheel. Brakes for motors below size 105 have single coil solenoids and the same general arrangement of brake parts as in the larger sizes. With this arrangement the top half of motor can be removed without disturbing the brake or solenoid.

The single coil solenoids have a normal gap of ¾ of an inch and the larger sizes of from 1 in. to 1½ in., depending on the size.

Double coil solenoids have air dashpots to prevent the moving core from delivering excessive hammer blows to the stationary parts. The solenoid and motor get current at the same instant (except in special cases), since both are connected through the first point of controller to line. Therefore in order to allow the motor armature to start at the instant it gets current it is necessary that the solenoid release the brake quickly. The dashpot does not prevent this, in fact it has no effect on the operation of the solenoid until its stroke—and consequently the release of the brake—is nearly complete. The air in the dashpot is then sufficiently compressed to have a retarding effect on the solenoid core, thus preventing destructive hammer blows.

The solenoids for ITC and MTC motors are the same as used on the MI and MD motors. Fig. 2 shows the arrangement for ITC-5008 up to and including 5011. This is the same arrangement as for the MI and MD motors, except that the lever is at the bottom, and the bracket for supporting brake parts is at the top. The frames of these motors are not split, and so there is no objection to this arrangement.

Standard brakes will hold from 50 to 75 per cent. of full load torque; this, however, can easily be increased in cases where additional holding power is required.

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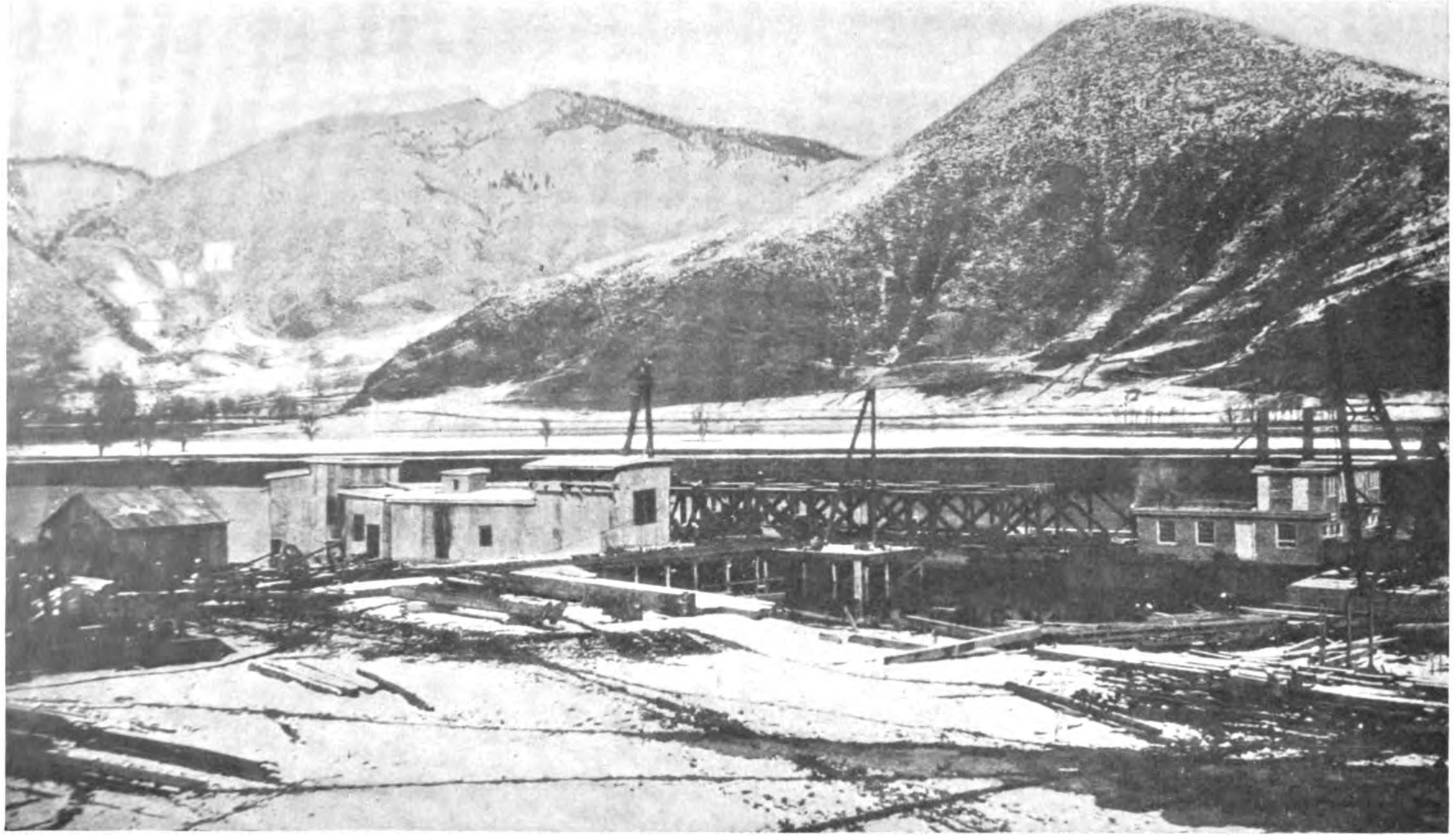

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GENERAL ELECTRIC REVIEW

THE TUNGSTEN LAMP

It would be almost impossible to find an electrical device which, in as short a time, has risen to occupy a position of such importance as the tungsten lamp. Whereas its carbon predecessor required many years to become a commercial success, the tungsten lamp in a mere fraction of this time has passed into almost universal utilization. During the relatively short period that has intervened since the lamps were first put out, their employment has increased with such rapidity that they now bid fair to well nigh replace all other varieties of incandescent lamps and have even encroached upon the former domain of the arc lamp in certain cases of street and interior lighting.

To the laity, the reason for the relatively high price of the tungsten lamp, as compared with the carbon, is a matter little understood. The principal reason is, of course, the difficulty attending the construction and mounting of the filament, which is very fragile and, on account of the conductivity of the material composing it, must needs be exceedingly fine and long, at least in the case of ordinary constant potential lamps. These, together with other peculiarities of manufacture, are discussed by Mr. Willcox in his article, "Some Interesting Features of the Tungsten Lamp." He shows that the methods employed with the carbon lamp cannot be applied in the case of the tungsten, the manufacture of the latter requiring very much more care and demanding a great deal of delicate, individual handwork; in fact, practically every operation in the manufacture of the lamp, from the production of the filament to the packing for shipment, is fraught with difficulty and requires special care.

In spite of these features, which of necessity add materially to the cost of producing the lamp, the great saving in current effected by its use will, in practically all cases, pay for the lamp in a very short time.

Based on this saving in current, Mr. Willcox gives in Table II the price that customers who have formerly received free renewals of carbon lamps, can afford to pay for tungsten lamps of different sizes. Table IV will also be of interest to customers, particularly the footnote, which shows that with a conservative life of 800 hours, a tungsten lamp will save from three to eight times its cost, depending upon the size of the lamp.

TABLES OF TRANSMISSION LINE CONSTANTS

On Pages 320-324 of this issue of the REVIEW we print the first of a series of tables for use in calculating high tension transmission lines. These tables have been prepared under the direction of Mr. David B. Rushmore, Engineer of the Power and Mining Department of the General Electric Company, and it is believed they are the most elaborate and complete upon the subject that have ever appeared in print.

No effort has been spared to render the tabulated results as accurate as possible, the tables being carried to the fourth and fifth place; the calculations having been carried to the seventh place in many cases to ensure accuracy in the retained figures.

The formulæ customarily used, and which involve approximations that lessen the labor of calculation at the expense of refinement, have not been employed. Accurate formulæ have been used wherever the error would otherwise have affected the result within the limits of the retained digits. The results have been checked by the method of second and third differences and by curve drawing, and it is believed that the number of errors cannot be large; but in a mass of figures of such magnitude, errors are liable to creep in and the editor will appreciate having his attention called to any which may be discovered.

The tables published in the present number are as follows: Self-induction for solid conductors; capacity for solid conductors; inductive reactance for solid conductors; for 25, for 60, and for 100 cycles. These will be followed in later issues by tables covering: Charging current for solid conductors, for 25, 60, and 100 cycles; inductive reactance 3-phase for solid conductors, for 25, 60, and 100 cycles; charging current 3-phase for solid conductors, for 25, 60, and 100 cycles. These tables, 14 in number, will be followed by a similar series for stranded conductors.

CENTRIFUGAL COMPRESSORS

The utilization of compressed air for a rapidly multiplying number of industrial applications is rendering the subject of blowers and compressors one of increasing interest.

The article by Mr. Callan, appearing in the present issue of the Review, leads up to a discussion of the centrifugal compressor by a brief description of the various types of air-supplying apparatus in general use; their function, and the conditions for which they may suitably be employed. He describes in this manner the propeller fan, the centrifugal fan, the rotary blower, the reciprocating compressor, and finally, the centrifugal compressor; which, he points out, is a development of the centrifugal fan, having, however, much greater range and better efficiency than has formerly been possible with this class of apparatus.

Mr. Callan's is the first of two articles upon the subject, and will be followed in the next issue by an article, by Dr. S. A. Moss, devoted wholly to a discussion of the centrifugal compressor.

RADIATION

In this number we print a lecture by Mr. W. S. Andrews, on the subject of radiation. In delivering this lecture, Mr. Andrews exhibits an interesting series of experiments to illustrate the characteristics of the various forms of radiation touched upon. These are fully described in the article, and while the experiments cannot be reproduced in print, the reader can at least view them with the mind's eye, by means of of Mr. Andrew's lucid descriptions of them.

Beginning with a general discussion of ethereal waves, the author passes to a description of the known waves of greatest length; *i.e.*, the Hertzian waves, having a frequency of the order of millions per second. He then takes up in the order of increasing frequency, the infra-red, or heat rays, with an approximate frequency of from 20 to 365 million millions per second; the visual light waves, which have a frequency of from about 365 to 800 million millions; the ultra-violet waves, of from 800 to 3000 million millions; and finally the group of waves of exceedingly small wave length and enormously high frequency, to which the X-ray ethereal pulses and probably the gamma rays of radium belong.

Of by far the greater part of these known waves our natural senses take no cognizance; it is only by means of ingenious mechanical help that we have become aware of their existence. The sense of sight, man's most highly developed sense and the one through which he learns most regarding the natural world, responds to but an infinitesimal part of these vibrations; the entire range from the shortest to the longest of visible light waves being little over one-thousandth of an inch, or from 0.43μ to 0.75μ.

Were this sense attuned to the long Hertzian waves, for example, we could view what is occurring in another continent; could follow the course of a steamer crossing the Atlantic; or could have witnessed the earthquake at Messina.

THE JHELUM POWER INSTALLATION

By S. Orling

His Highness, the Maharajah of Jammu and Kashmir, has given an unmistakable proof of his enlightened and progressive policy and of his earnest desire to benefit his country by deciding to introduce electric power to his remote parts of India.

Fig. 1. The Maharajah of Jammu and Kashmir

The valley of Kashmir is situated in the midst of the western Himalayas, its mean height being approximately 5000 ft. above sea level. Surrounded by huge mountain ranges, the river Jhelum, which flows through the valley, does not afford sufficient outlet for the immense masses of melted snow coming down from the hills during the spring. The result is that serious floods occur every year, submerging for several months thousands of acres of land.

To render available for agriculture these tracts of land, which are now unsuitable for that purpose, would be of great benefit to the state. Accordingly, the Kashmir Durbar decided to dredge out the river, starting at Baramula, where it becomes narrow and gorgelike, and working up towards Srinagar, the capital, for a stretch of about 30 miles, the amount of dredging necessary to regain 200,000 acres of land being about 5,700,000 cu. yds.

Since coal is not available in Kashmir, and since the site where the dredging was to be done is nearly 200 miles from the nearest railroad station, electric energy was decided upon for the driving of the dredges. The river gives an ample supply of water throughout the year, and a hydro-electric plant was therefore erected for supplying the power. The plant was built at Mohora, 21 miles south of Baramula, with an available working head of approximately 400 ft. and an ultimate capacity of 20,000 h.p., of which but 5,400 h.p. is at present utilized. After a careful consideration of the topographical conditions, it seemed advisable to construct a canal 6½ miles long with a uniform grade of 1.05:1000, and by so doing obtain a head on the wheels of 400 ft.

At the intake there are ten main sluices in two tiers, one above the other, for use at high and low water levels, the capacity of these being over 600 cu. ft. per second with the minimum head available at low water. The main sluices are provided with steel gates and screw-gearing for operating, and discharge into a small regulating basin giving admittance to the supply channel. The scour sluice has four vents, each 4 ft. by 7 ft. All vents are protected by heavy iron gratings and a grid barrier of rails erected vertically across the channel, which, together with securely anchored floating timber booms, afford ample protection from damage by passing timber and debris, large quantities of which are floated down the river each flood season.

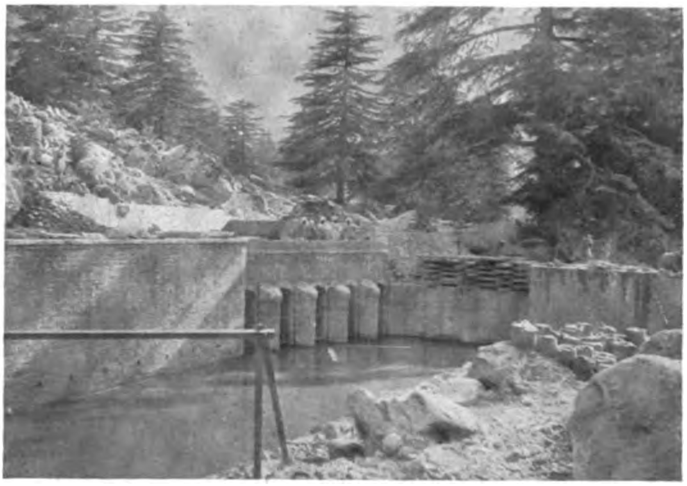

Fig. 2. Head Works

A wooden flume presented the only practical method of conveying the water along the steep hillsides, which are generally of shaly formation with slopes averaging 1 in

1¼, although where conditions allowed a masonry lined and floored duct was constructed. The whole supply channel is made up as follows:

Masonry	1.57	miles
Silt basin	0.11	"
Timber flume	4.67	"
Rock tunnel, unlined	0.15	"
Total	6.50	miles

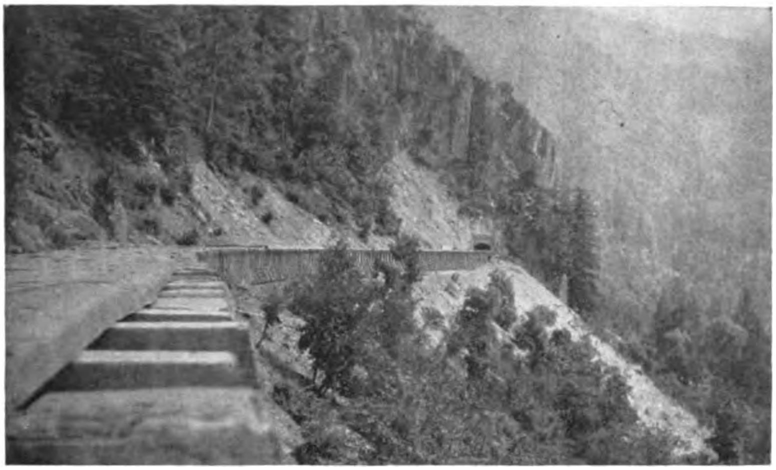

Fig. 3. A Section of Flume showing Steep Hillsides on which it is Built

The masonry lining averages 2 ft. in thickness, and is lined with a back filling of clay concrete; while the floor is 6 in. thick and is sublaid with concrete of 6 in. minimum thickness. There are six tunnels of an aggregate length of approximately 2000 ft., through many of which the timber flume is carried, and five large aqueducts bridging gorges.

The silt basin, which is a most essential adjunct, has been constructed at a point about 4000 ft. from the head works. It is proposed shortly to install a floating sand pump plant with portable engine to periodically clear silt from the 40 ft. deep pocket at the bottom of the basin, as required.

The track on which the flume is built has very much the form of an ordinary hill road. A continuous retaining wall of coursed rubble, laid dry and battered 1 in 4 to 1 in 3, supports the hillside; a drop wall of similar construction protecting the outer edge of the track from erosion, etc. The minimum width of the track is 12 ft. and it is macadamized throughout. The under sides of the caps are canted at the outer ends around sharp curves to counteract centrifugal wave effect. The minimum radius of curves on the line is 50 ft.

At two places it was necessary to build very heavy timber floors, or aprons, over the flume, and support them by substantial crib work abutments of logs and stones, to protect the flume against heavy trees and drift timber that sweeps down the ravine during prolonged periods of heavy rain. Snow sheds had to be constructed at three different points where snow drifts are known to be exceptionally heavy.

The dimensions of the rectangular flume are 8 ft. 4 in. by 8 ft. 6 in., giving a capacity of nearly 600 cu. ft. per second at full depth of flow and a velocity of little more than 8 ft. per second; this rate of flow being equivalent to over 18,000 h.p. at the power house.

The forebay has been constructed for the full capacity of the power plant, the large tapered inlets for future extension having been closed with brick work. The water passes over the spillway into a waste duct extending around the mountain side to a "nullah."

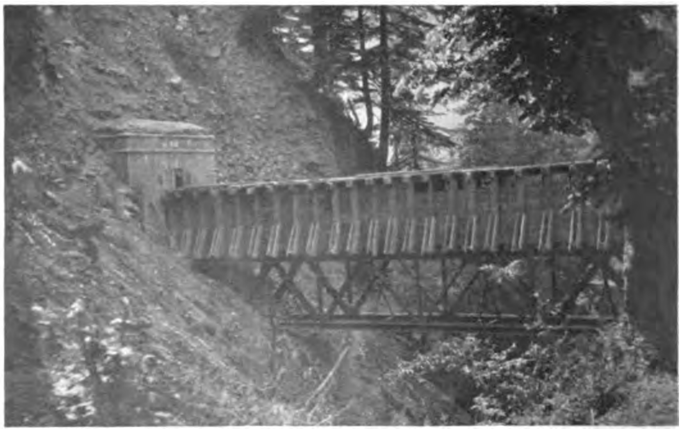

Fig. 4. The Flume Carried Across a "Nullah"

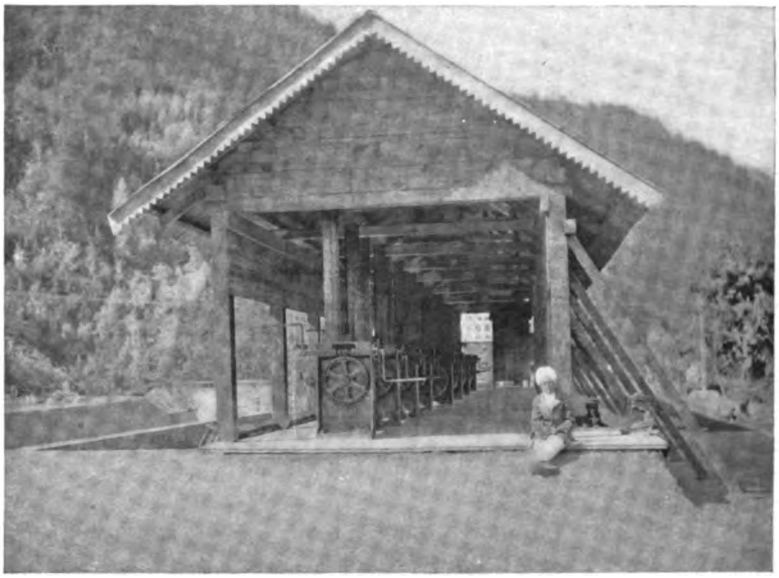

Fig. 6. Forebay

The penstock pipes are 750 ft. long and consist of welded steel 30 in. in diameter and $\frac{3}{16}$ in. thick in the upper section; and 36 in. in diameter and $\frac{5}{16}$ in. thick in the lower section. Where the pipes are above ground level, they are supported by brick work piers spaced with 20 ft. centers, measured along the slope.

Four Doble impulse water wheel units with automatic oil pressure governors are installed, while tail races and additional transformer compartments for four more units of similar capacity have been built. At the upper end of the tail races, where the jet discharges almost perpendicularly downwards, flat steel plates are set in the concrete.

Each unit is guaranteed to deliver 1,765 h.p. to the shaft at 500 r.p.m. under an effective head of 400 ft. The needle regulating nozzle is controlled by hand and the nozzle is provided with a jet deflector which is operated by an automatic governor for the control of sudden load fluctuations. The nozzle is of the duplex type, two jets being provided for each wheel. The needles are usually set for that size of the jet which will develop the maximum peak load expected for any particular period of the day. At full gate the guaranteed wheel efficiency is 77 per cent.

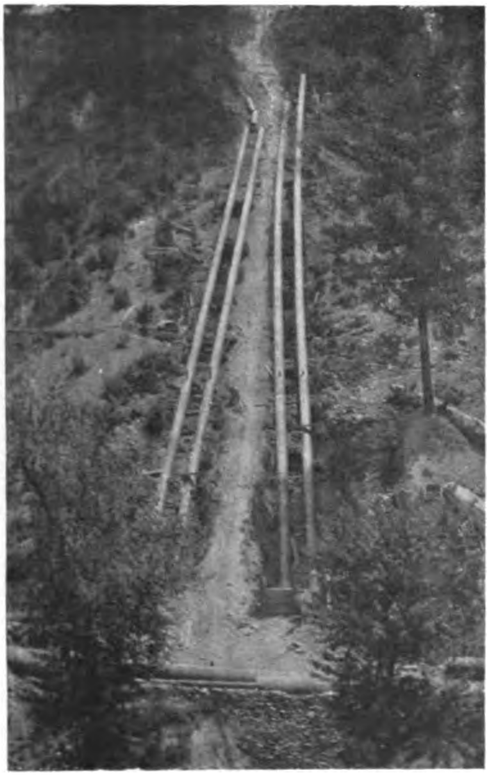

Fig. 5. Penstocks under Construction

The generator plant consists of four General Electric three-phase, 25 cycles, 6-pole, 1000 kw., 500 r.p.m., 2300 volt, revolving field generators, and two 6-pole, 150 kw., 500 r.p.m., 125 volt exciters.

The exciters are direct connected to 250 h.p. individual water wheels of the impulse type, located in the middle of the station below the switchboard gallery. Close to these is an impulse wheel driving a 35 kw., 125 volt direct current generator used for station lighting and for charging a storage battery supplying power for the electrically operated switches. On the other end of the waterwheel shaft is coupled a 50 h.p. induction motor, which is connected directly to the 2300 volt bus bars. The waterwheel is continuously run with its valve open, as for full load. When less than full load is on the generator, the induction motor runs as a generator; but if for any reason the waterwheel fails, the motor will drive the exciter. This precaution is taken to avoid a failure of the station power and lighting supply in case the nozzle of the waterwheel becomes choked, which incident sometimes occurs with such small wheels at high heads.

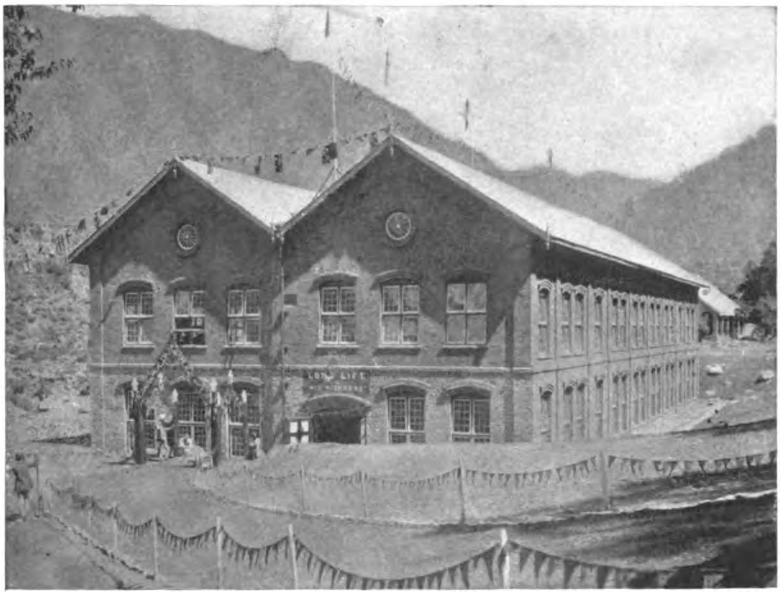
Fig. 7. Power Station

There are six step-up compound wound transformers arranged in two banks, with primaries and secondaries connected in delta. The transformers are oil insulated and water cooled, and each is rated at 1000 kw., 25 cycles, stepping up the voltage from 2300 to either 60,000 or 30,000 volts.

The switching apparatus is of the remote control type, with electrically operated switches installed in masonry compartments, and bus bars similarly protected. Solenoid operated oil switches are used on the 2300 volt circuit and motor operated oil switches on the 60,000 volt circuits, all being operated by 110 volt direct current and controlled from a central controlling board of the bench board type, which is located on the gallery about the middle of the main generator room. The control apparatus consists of the following:

Generator control benchboard.
Generator instrument board direct connected to the benchboard.
Exciter control switchboard.
Transformer control benchboard.
Transmission line control benchboard.
Tirrill regulator and station lighting switchboard.

The benchboard accommodates four sets of operating handles for the generator main switches, four sets for the transformers, two sets for the 60,000 and 2300 volt bus bars, and two sets for the transmission line, the last being all on one end of the benchboard. The generator field switchboard is located below the main switchboard.

The main transformers, as noted above, may be connected for either 30,000 or 60,000 volts, and the switchboard is so designed that the plant may be run at either voltage.

The equipment for lightning protection consists of two sets of multiplex type arresters, one for each outgoing line.

At one end of the power house a well equipped machine shop has been provided, also a complete oil treating plant for removing

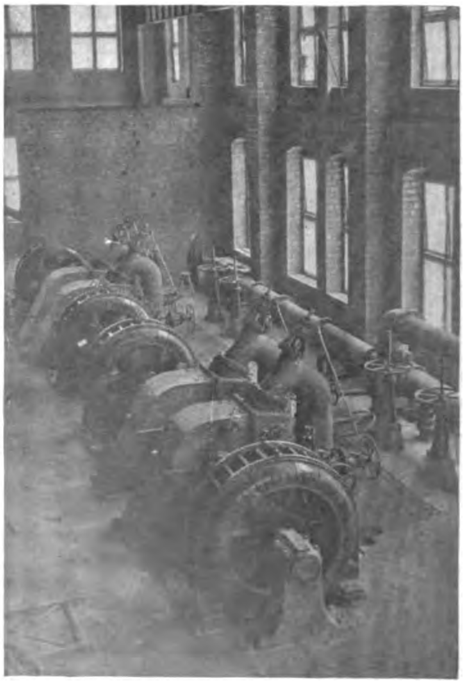
Fig. 8. Interior of the Power Station

all traces of moisture from the oil used in the high tension transformers.

There are two outgoing, independent, three-phase, 60,000 volt transmission lines, one ending at Baramula, 21 miles distant, the other continuing to Srinagar, 50 miles from Mohora. The standard height of pole is 35 ft., with a spacing of 175 ft. The conductors consist of 6 strands of No. 8 copper wire with jute core, strung on 60,000 volt insulators so that the section of the line will show an equilateral triangle, the sides of which are each 6 ft. The transmission line crosses the river five times within five miles of the power house. The line construction is very substantial, native timber, mostly deodar, being used throughout for poles and crossarms. Instead of one pole for each three-phase line, two poles are used, set about 12 ft. apart and tied together by two 6 in. by 6 in. crossarms, the upper arm carrying one, and the lower, two of the transmission cables. Two grounded 6 strand iron cables provide lightning protection to each three-phase transmission line. These are fastened to the tops of the poles on each side, about 6 ft. from the upper conductor of the line.

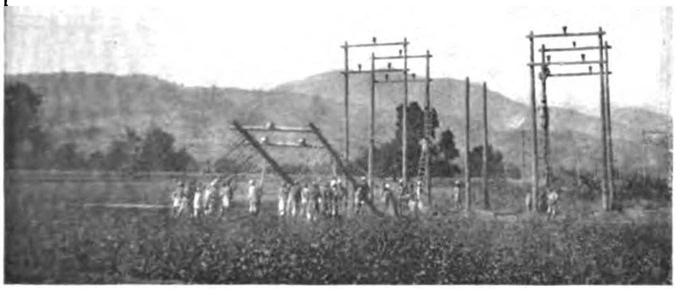

Fig. 9. Transmission Line Showing Method of Raising Poles

The insulators are of porcelain brown glazed, 4-part, 14 inches in diameter. Before shipment, the four parts were tested separately at 40,000 to 60,000 volts for five minutes, and the completed insulator at 120,000 volts for ten minutes. Breakage was entirely avoided by packing each insulator in a heavy crate.

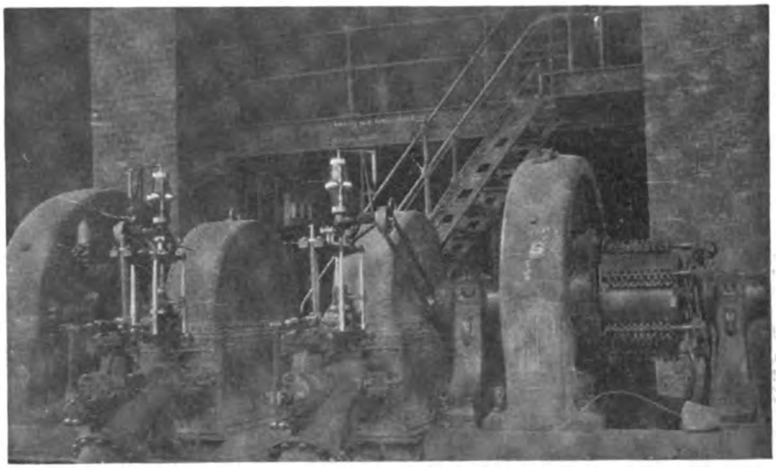

Fig. 10. 150 Kw. Exciter Sets

A metallic circuit telephone line consisting of stranded galvanized iron cable (6 No. 12 B. & S.) is run on a small cross arm 3 ft. below the lower line cross arm and is transposed at every pole. The instruments are protected by telephone transformers. At Baramula both lines are so arranged that the Baramula line can be switched over to the Srinagar line in case of necessity. At this point, the former line branches off to the river to supply the dredging plant with power.

The dredging plant is unique in being electrically driven, and consequently contains many interesting features. It comprises the following outfit:

Two floating 60,000 volt substations.
Two hydraulic dredges.
One dipper dredge.
Two clam shell type stiff-leg derricks.

The two floating substations, Nos. 1 and 2, are of 1200 kw. and 600 kw. capacity, respectively; No. 1 being equipped with six oil insulated, self cooled, 25 cycle, 200 kw., 60,000/30,000–2300 volt step down transformers, and No. 2 with three transformers of the same capacity.

The incoming high tension lines enter through 60,000 volt wall bushings, the wires being heavily insulated with varnished cambric to a distance of 30 inches beyond the porcelain tube on either side. The wires drop down through choke coils and branch off through six combined expulsion fuses and disconnecting switches carried on insulators supported from the substation roof and located directly above the two banks of transformers, one on each side of the station. On the opposite wall to the incoming line, the 60,000 volt multiplex type lightning arresters are located, the wires being carried across the station from the incoming line. In the center of the station, and at the height of the transformers, a platform is built from which the operator can easily reach the switches on both sides of the room by means of 8 ft. wooden rods. The primaries and secondaries of the transformers are both connected in delta, the primary leads dropping down to the transformer terminals from the high tension wires above. The secondary connections are made through wires carried along on the wall on both sides of the substation. These wires continue to the low tension switchboard, one panel for each bank being equipped with a triple-pole oil switch which connects each bank of transformers to the low tension bus bars. To the latter, six air brake single pole disconnecting

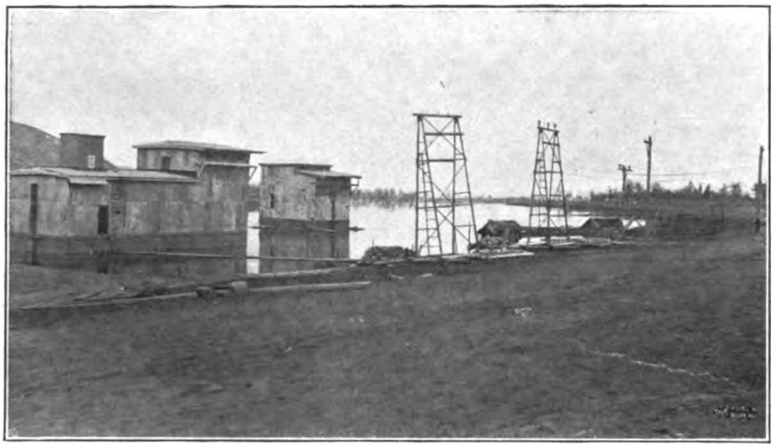

Fig. 11. Floating Substations No. 1 and No. 2

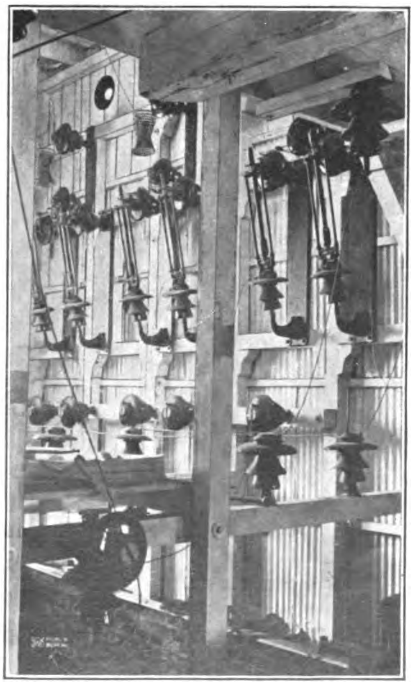

Fig. 12. Interior of Floating Substation No. 1 Showing Combined Expulsion Fuses and Disconnecting Switches

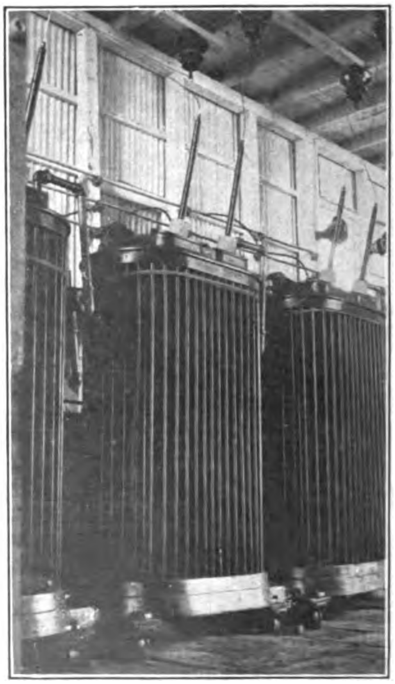

Fig. 14. Interior of Floating Substation No. 1 Showing Arrangement of Transformers

switches are connected, three for each outgoing low tension line.

The transformers are mounted on wheel trucks. One pair of rails runs along the length of the substation, and three pairs at right angles run across the whole width of the floor. The height of the main roof is not sufficient to allow of lifting the transformer out of the tank. A special place at the low tension end of the station had to be provided for this purpose.

In the center of the room a section of the roof 7 ft. square had to be raised about 8 ft. and a substantial wooden structure erected which extends to the floor and will safely carry 3000 lbs. All transformers were assembled in the station.

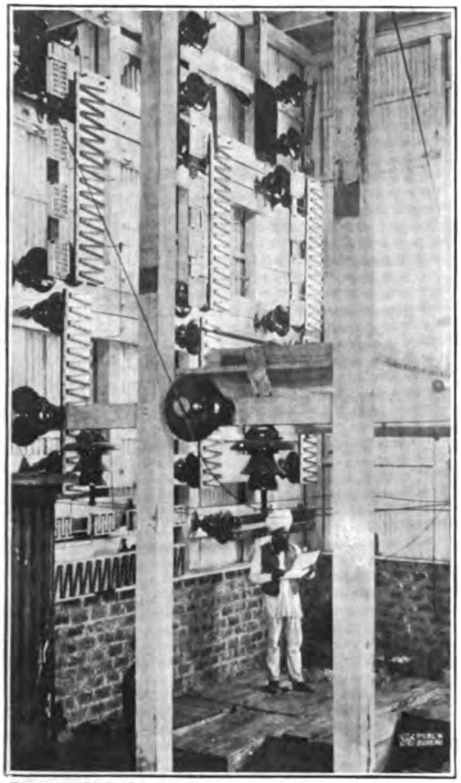

Fig. 13. Interior of Floating Substation No. 1 showing 60,000 Volt Lightning Arresters

The outgoing low tension wires are connected to three 2300 volt feeders running along the shore, from which lines are tapped off to the dredges at different places as the latter work up the river. Since the dredging covers some 30 miles, it is easily understood why a floating substation is necessary.

The other floating substation is arranged in a somewhat similar way to the one described.

(To be Continued)

RADIATION

By W. S. Andrews

The term radiation is usually and properly applied to manifestations of activity in the universal ether, such as heat and light, and it is also occasionally used in connection with phenomena caused by the rapid flight of minute particles of electrified matter, as, for example, in connection with cathode rays and the alpha and beta rays of radium, etc.

It is a matter of common knowledge nowadays that heat and light, as manifested to our senses, are caused by minute waves or ripples in the universal ether, and that the only difference between them is that the waves which produce heat without light are of greater amplitude and lower frequency than the waves which produce in our eyes the sensation of light.

It is probable that the infinite expanse of the universal ether is agitated by waves and ripples of all imaginable amplitudes and frequencies, the extremes of which may never be revealed to us. In fact, those waves which are manifested directly to our senses, as in the case of heat and light, together with those which are made known to us indirectly by their effects, like the Hertzian waves of low frequency that are used in wireless telegraphy, only occupy what may be considered as a few octaves here and there on the immeasurable keyboard of the universal ether. These waves in the ether which produce heat, light, chemical action, etc., all travel through space with a velocity of about 186,000 miles per second, and they are all subject to the same optical laws; that is, they can be reflected, refracted, dispersed, polarized, etc.; so they may all be fairly termed light waves, if you please, although they are for the most part invisible, because our eyes are only constituted to perceive waves within a certain limited range of frequency.

Having thus very briefly generalized some of the physical properties of ether waves, we may now venture to specialize, starting as low as possible down the scale and tracing the waves upwards as they increase in frequency and diminish in amplitude.

Nearly half a century ago Clark Maxwell proved by mathematical deductions that ether waves must have an electro-magnetic origin, the idea having been foreshadowed by Faraday at an earlier date. About 25 years later this theory was reduced to practice and its truth was demonstrated by the well known and classical experiments of Prof. Hertz.

Vibrations and waves can be easily produced in water, air and other material substances by mechanical disturbances, but the universal ether can not be acted on in this way. We can, however, stir the ether into action by the production of heat, as in the burning of inflammable substances like wood, coal, or gas, or by raising the temperature of an electric conductor by passing current through it, as in the case of an incandescent lamp or an electric heater. We can also get a grip upon the ether, so to speak, by magnetism, without any appreciable heat and thus produce in it waves and ripples.

Let us suppose, for example, that we have an electro-magnet, connected to a source of electricity through a device capable of making and breaking the circuit with any desired frequency. On *making* the circuit, a magnetic field is produced which radiates into space with the velocity of light, and on *breaking* the circuit the magnetic field collapses and disappears. If the circuit were to be made and broken regularly every second, a series of waves would be propagated in the ether, and the length of each wave would obviously be about 186,000 miles from crest to crest; or if it were possible to make and break the circuit 186,000 times per second, the magnetic waves would be about a mile long from crest to crest, and so forth.

It would naturally be impossible to make and break an electric circuit by mechanical means with sufficient rapidity to produce even the comparatively long Hertzian waves that are used in wireless telegraphy, and I have only cited the illustration of the electro-magnet and circuit breaker to convey a simple conception of the origin and propagation of such waves.

These low frequency waves in the ether can, however, be conveniently generated by disruptive sparks between the terminals of a condenser which is charged from some source of high potential electricity, such as an induction coil or a high voltage alternating current transformer. I have here an induction coil connected with a condenser, and when I close the switch you see a stream of brilliant and noisy sparks passing between the terminals. This discharge appears to the eye like a continuous luminous stream, but it actually consists of a rapid succession of separate sparks oscillating to and fro between the terminals. Each of these individual sparks causes a wave in the ether, and a train of waves which naturally correspond in frequency to the oscillations of the electric sparks is thus formed. When the regular order of these waves in the ether is interrupted by opening the circuit at irregular intervals, and the ether waves are intercepted by a suitable device, they produce effects which can be interpreted into intelligible signals and thus made to convey messages through space without wire conductors. The signals of the Morse or any other telegraphic code can thus be produced by the manipulations of an ordinary telegraphic key, the key offering a convenient means of making and breaking the circuit in the primary winding of the coil, thus imitating the dots and dashes of the code by sparks of longer or shorter duration.

The frequency of ether waves thus produced may be reckoned in millions per second, and they may vary in length, according to their frequency, from a few inches up to hundreds of yards.

Passing upwards on the scale we find the next series of waves that are manifested to us by their physical effects to be the heat waves, but between the latter and the low frequency Hertzian waves there is a wide gap including many octaves of waves, the physical properties of which are at present unknown; for, as before stated, the frequency of the shortest waves used in wireless telegraphy may be counted in millions per second, while the heat waves only begin with frequencies of millions of millions per second.

I may here digress a moment to state that not more than about a century ago heat was believed to be an imponderable essence called "phlogiston," with which all matter was supposed to be impregnated to a greater or lesser extent, and which could be transferred from one substance to another, thus imparting degrees of heat in proportion to the amount of phlogiston absorbed.

Light also was at that time believed to be caused by small particles or corpuscles which were expelled in great quantities by luminous bodies, such as flames, etc., and which, upon striking non-luminous objects, rebounded therefrom, and on entering the eye produced the sensation of light. This was called the "corpuscular theory of light" and it was originated and stoutly championed by the great Sir Isaac Newton. Nobody ever imagined in those days that heat and light were only different manifestations of one universal medium, and indeed, who would be likely to suppose from any superficial observation that two sensations so radically different could have a common origin!

And yet, when we stop to consider that both heat and light generally emanate from the same source and that at a certain point they are so blended together as to make it difficult to determine exactly when the light from a hot body is first actually discernible to the eye, it seems as if the close relationship between heat and light might have been recognized at an earlier date.

Beginning with a frequency of about 20 billions* per second, Langley mapped out the spectrum of dark heat waves up to a frequency of about 365 billions per second, where the first red rays of visible light begin to appear, showing that the dark heat, or infra-red spectrum, extends at least five octaves below the visible spectrum, and possibly even further.

These invisible heat waves are not in themselves hot, nor do they heat any medium which is transparent to them when passing through it, but when they are *intercepted* and *absorbed* by any substance, the latter is heated. If they strike a bright surface like a mirror they are reflected and pass off in another direction just as visible light waves would do, but rough surfaces, especially if black or dark colored, absorb them and sensible heat is produced, the wave motion in the ether being then changed to molecular or atomic vibrations in matter.

The terms heat rays, light rays, chemical rays, etc., are really misnomers, as Dr. Steinmetz has pointed out, because they only convey the narrow interpretation of our senses in relation to effects produced on matter by the absorption of waves in the ether which differ from each other only in frequency and amplitude, and which develop no physical effects until they are absorbed by a material body. These terms, however, serve to identify the waves of different lengths and frequencies in a popular sense, so I shall continue to use them for the present, having the above explanation in mind.

We all know that heat rays pass readily through a vacuum, and yet a vacuum is the very best heat insulator in nature. At first this may appear like a contradiction, but on reflection it becomes evident that these apparently contradictory properties arise only from our having confused *cause* with *effect*; the cause of heat being the waves in the ether, and the effect being the sensible heat which these waves produce in any material substance by which they are intercepted and absorbed. A vacuum cannot conduct heat, because heat is a material phenomenon and can not exist outside of matter; but the ether waves which produce this heat pass readily through a vacuum. If, therefore, a hot body is surrounded on every side by a vacuum it can only lose its heat by radiation, and as the latter is inconsiderable at comparatively low temperatures, hot bodies that are thus surrounded lose their heat very slowly; and *vice versa*, cold bodies absorb heat very slowly, as shown, for example, in the well known Thermos bottles, and the vessels used for storing liquid air.

I will close my remarks on heat by showing you two simple experiments illustrating, first, how surface conditions vary the receptivity of a body for heat waves, and second, how these same surface conditions govern the radiation of heat therefrom.

I have here a paper screen in a wooden frame. The paper is covered on one side with common gold bronze and in the center there is a round spot of dead black paint applied over the bronze. The other side of the paper is coated with a sensitive paint made of a double iodide of mercury and silver. This preparation has the property of changing from a light yellow color to a dark orange or brick red at a temperature of about 45 C., returning to its original light yellow color on cooling. We have a source of heat in the large incandescent lamps in this luminous radiator. I will hold the paper screen before the radiator with the sensitive paint side towards you, and you will notice that a round spot in the center of the screen turns red while the rest of the surface remains unchanged in color. The obvious reason for this is that the gold bronze on the reverse side of the screen reflects the heat rays, thus diverting them to a large extent so that they do not heat the paper, whereas the round spot which is painted black absorbs the heat rays, and the heat, passing through the screens, changes the color of the sensitive paint.

Here is another screen, made like the first one, excepting that on one side the entire surface is painted black and the round spot in the center is covered with gold bronze. On heating this screen before the luminous radiator, the former effect is naturally reversed and we see a light yellow spot on a red background.

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* A billion is here taken to be a million millions.

I will now illustrate how surface conditions govern the radiation of heat. I have here what is termed a differential thermometer, which is simply a "U" shaped glass tube partly filled with a colored liquid and tipped with two glass bulbs which are painted black to enable them to absorb heat rays readily. The cross tube with glass stop cock serves as a convenient means for equalizing the pressure in the two bulbs. If I put my hand on one of the bulbs, the air within expands with the warmth and depresses the colored liquid below it, thus causing it to rise correspondingly in the other tube. Between these two glass bulbs there is a plate of aluminum which can be electrically heated, one side of this plate being brightly polished and the other side painted black. . . . .

On connecting this device to the circuit it becomes hot, and the surface which is painted black radiates more heat than the polished surface, or, in other words, it loses its heat more rapidly, as evidenced by the depression of the column of colored liquid. We may thus trace the reason for the old saying that "the polished kettle boils the quickest" and we may also apply our knowledge of radiation to the painting of the hot water and steam radiators in our houses.

Passing now from the spectrum of the dark heat rays to the luminous spectrum, we find, as before stated, that the first red rays of visible light are produced by waves in the ether having the almost inconceivable frequency of about 365 billions per second. It is easy to talk of this number or to write the figures 365 followed by twelve ciphers, but the human mind is almost incapable of realizing such tremendous values.

The principal source of artificial light from time immemorial has been carbon, raised to a high point of incandescence by chemical or electrical energy, as for example in the pine knot, the torch, the candle, the kerosene lamp, and the gas flame, as well as in the ordinary carbon arc light, wherein one or both of the carbon tips are raised to a high incandescence by the same means, and gradually waste away. In all of these sources the light is produced by minute particles of carbon raised to intense incandescence by vigorous chemical combination with the oxygen of the air. In the case of the incandescent lamp, a filament of carbon or other material is raised to a high temperature in a vacuum, by the passage of an electric current through it, the filament remaining unconsumed because there is no oxygen present to combine with it.

All these various sources of artificial light are very inefficient as light producers, because a large percentage of the chemical or electrical energy consumed is transformed into invisible heat rays, which are not wanted and which may therefore be regarded as a *waste product*. Taking the carbon filament incandescent lamp for example, its light giving efficiency is usually less than 2 per cent. and never more than 3 per cent. Now it is very obvious that when 97 or 98 per cent. of the total energy used is practically wasted in making something that is not wanted, the useful product naturally becomes costly.

There are methods, however, for producing cold light; by which I mean the propagation of ether waves of a frequency wholly within the visible spectrum, not burdened with a lot of invisible and useless heat waves. If a practical illuminant of this order could be devised it would certainly revolutionize our present wasteful methods of artificial lighting.

The Moore vacuum light, which is an attempt in this direction, is simply a Geissler tube on a large scale which generates a considerable amount of light with only a small amount of heat as compared with an incandescent lamp.

I have here a glass tube about four feet long and two inches in diameter which is connected by a rubber tube with the air pump. The two metal terminals of the tube are connected by small wires to a high tension transformer which raises the 120 volt alternating current of the lighting circuit to about 5000 volts. The tube being now full of air, no current can pass between the terminals, and consequently no light is visible. I will now start the air pump, which will gradually draw out the air, and I wish to call your attention to the wonderful changes in character and color of the electric discharge through the tube as the exhaustion proceeds. First we see a faint electric glow at the two terminals; then a dim line of light appears throughout the tube, which increases in extent and brightness as the vacuum becomes higher, until it fills the tube with a beautiful rose colored hue. Now the vacuum is still higher, and the light is losing its rosy tint and getting white, and now it is almost pure white and much brighter.

At this point I will stop the pump, as the best degree of vacuum for lighting effect has been reached, and further exhaustion would be useless. Although this tube is of fairly large size, its best illuminating power is weak, and its length would have to be increased many times before it would light up this hall as brightly as a few incandescent lamps. It may, however, be considered as a fair representation of the Moore vacuum light on a small scale.

The mercury vapor lamp produces a much brighter light than the Geissler tube, but it is almost entirely lacking in the red rays of the spectrum, so that in general, objects which in white or yellowish light exhibit various shades of red and its compound colors, appear in unnatural colors under this light. It brings out shades of green and blue, however, in vivid beauty, and it is therefore suitable for outdoor illumination, especially when the trees are in leaf.

All vacuum tubes of this character, however, generate a certain amount of heat, which, as stated before, may be considered as a waste product because it is not wanted; and therefore these tubes fail to represent the most efficient type of illuminant, which should generate only the useful light waves, or those waves which exist within the luminous spectrum.

We are not able at present to economically produce cold light of sufficient power to render it commercially serviceable. We can, however, make a weak light of this character, as I will show you presently, and it is to be hoped that we may some day be able to produce artificially the "cold" light of the firefly and the glow-worm on a large scale. The light of the sun is made up of a mixture of all the colors of the rainbow, so wonderfully and beautifully blended as to constitute white light, and in producing artificial light, it is evident that we should aim to make it resemble sunlight as closely as possible.

We speak of red or yellow or blue flowers, or green leaves, but we all know that neither the flowers nor the leaves have any intrinsic color in themselves, but that they, as well as all other objects in nature, which are not self-luminous, only reflect innumerable colors and tints, which are borrowed from the light that makes them visible.

The wonderful molecular structure of various bodies causes them to absorb light waves of certain frequencies and reflect other rays, and it is the infinite variety of combinations of the primary colors thus produced that create the innumerable shades and color tones which render nature so beautiful. Thus leaves are in general green because they reflect the green rays together with other component rays which vary their particular shade of green, and absorb the other rays; while a red object on the other hand reflects the red rays and absorbs those of other colors. If for some reason the sun and all other sources of light should cease to emit light waves of the frequency which produce the sensation of red in our eyes, this color would naturally vanish from the face of nature, no matter how brightly illuminated by the light of other colors. Under these circumstances the shades of all colors having red as a component would be more or less changed, and all objects which are so constituted as to reflect only pure red light would appear black, because there would be no red rays for them to reflect, and black is known as the absence of all reflection.

Pure colors are rare in nature, however, and moreover it is difficult to produce artificially a light of any intensity in which any one of the primary colors is totally absent. The mercury vapor lamp, for example, emits a few red rays, but these are very weak, so that objects which appear in different shades of red by ordinary light, show marked changes in color under the light of this lamp. I have here several paper screens which, as you see by the light of the incandescent lamps, show different shades of red. Now by the light of the mercury lamp, all other lights being extinguished, you see that one of these screens is almost black while others show different shades of gray or slate color.

It is thus evident that color is not an inherent quality in any non-luminous object but is only the reflection of a part of the light by which it is illuminated. Yet strange to say, there are certain objects which appear red or pink under the light of the mercury arc. I have here a pasteboard disk which is colored red with an aniline preparation called rhodamin. One-half of the disk is painted with rhodamin dissolved in alcohol, and the other half with copal varnish colored with rhodamin. By the light of the incandescent lamps you may observe that there is not much difference in color between the two halves of the disk, but when seen by the mercury lamp alone, one half shows a bright pink while the other half is a bluish black. This appearance of a bright pink color under a light which emits practically no red rays, appears to contradict my previous statements, but it really introduces us to a very curious and wonderful phenomenon known as "fluorescence," which we will now proceed to examine, leaving the rhodamin disk to be referred to again later on.

As before stated, the visible spectrum is produced by ether waves commencing at the extreme red with a frequency of about 365 billions per second, increasing in frequency up to about 800 billions per second in the extreme violet. Beyond the extreme violet there exists a spectrum of two octaves or more of invisible rays produced by ether waves of ever increasing frequency and diminishing amplitude, commonly termed the "ultra-violet rays." These rays produce strong chemical reactions, such, for example, as the blackening of silver chloride paper, and they also possess many other curious properties. I have here a lamp in which light is produced by an electric arc between iron terminals. The light thus generated is very rich in the invisible ultra-violet rays. The iron arc also emits a considerable amount of visible light which must not be mistaken for the ultra-violet rays, as our eyes are incapable of detecting the latter. These invisible rays have been found to exert a marked effect on animal organisms, and I believe the honor of this discovery, or at least its practical application to the alleviation of human ailments, is due to the late eminent scientist and physician Finsen, whose name has very appropriately been given to the lamp which produces these healing rays so abundantly. It is now well known that sufferers from malignant skin diseases who have failed to receive benefit from ordinary medical treatment have been completely cured by ultra-violet light.

I will now show you how the rays from this lamp affect silver chloride paper such as is used in photography. Holding the lamp over a sheet of this paper you will note that it turns black very rapidly. It is not, however, the visible light that produces this effect, for when I interpose a sheet of mica no thicker than a piece of writing paper between the lamp and another sheet of the silver chloride paper the latter does not now even darken, although you can see that the mica intercepts hardly any of the visible light. A piece of plain window glass or a thin sheet of transparent gelatine produces the same effect as the mica, all of these substances being opaque to the ultra-violet rays although transparent to visible light rays. I will now repeat the experiment by interposing a plate of clear quartz crystal between the paper and the light; this time the paper immediately darkens because the quartz is alike transparent to the visible and the invisible rays. There are also other substances which resemble quartz crystal in this respect, and I will again repeat the above experiment, using this time, instead of the quartz, a plate of selenite, which is a natural carbonate of lime. Although the selenite is fully a quarter of an inch thick you will see that the invisible actinic rays pass through it freely, as evidenced by the instant darkening of the silver chloride paper; and yet this darkening was completely prevented by a piece of mica no thicker than a sheet of note paper.

I think I have now clearly demonstrated that it is the invisible ultra-violet or actinic rays from this lamp which produce the chemical reaction in the silver chloride paper, and we may therefore proceed to examine some of the other curious properties of these rays.

There are certain chemical compounds which possess the peculiar property of changing ultra-violet rays into lower frequency waves of visible light. These substances are in fact frequency changers of light waves in the ether. When this effect is transient, that is, when it exists only while the substances are excited by the ultra-violet rays, it is called "fluorescence"; and when it is persistent, that is, when the effect continues after the exciting rays are cut off, it is termed "phosphorescence." Although fluorescence and phosphorescence are closely allied phenomena, they differ in one important feature, in that phosphorescence, besides being capable of excitation by ultra-violet light, can also often be produced by ordinary visible light and even by the invisible heat rays of the infra-red spectrum; whereas fluorescence can be produced only by the invisible ultra-violet rays and is visible only while the fluorescent substance is under their influence. In some cases phosphorescent light continues to shine for hours, whereas in others it only lasts for a small fraction of a second and can only be detected by special apparatus. I will now show you some examples of fluorescence and phosphorescence.

I have here some cardboard screens painted over with different chemicals and minerals in a fine powder, all of which appear nearly white by visible light, but which fluoresce with different characteristic colors when excited by the ultra-violet rays. Thus, this screen prepared with willemite, which is a natural silicate of zinc, glows with an intense and brilliant green, while this one, prepared with calcite, which is a natural carbonate of lime, shows a pink color. These other screens, which are covered respectively with soda salicylate, calcium tungstate and calcium sulphide, exhibit various shades of blue. I will now interpose a thin sheet of mica, as before, between the lamp and the screens, and you will see that all the colors disappear instantly and the various preparations are white again as they appear under ordinary light, once more showing that it is the invisible ultra-violet rays, to which the mica is opaque, that produce the fluorescent colors. Here are some outlines representing plants and flowers, etc., which are painted over with the different preparations mentioned. They show no colors whatever by the light of the incandescent lamp, but under the ultra-violet rays the leaves are green, the flowers red and blue, etc. I interpose a piece of plain window glass, and presto! the colors are all gone! and the leaves and flowers are white again!

I will now show you some examples of phosphorescence, this time using the mercury lamp instead of the iron arc, and will expose to its rays some objects which have been painted over with phosphorescent calciumsulphide.

Here is a little rabbit made of white plaster, thus prepared. After exposing it to the light of the mercury lamp for a few seconds we will turn out all the lights. You now see the rabbit shining weirdly with its own light, and looking something like what an ignorant person might imagine to be a rabbit's ghost; in fact, credulous people have often been deceived into fancying they have seen supernatural objects by similar phenomena.

On this card I have reproduced a fairly good likeness of our immortal Benjamin Franklin, in phosphorescent paint on a black background, and you may now readily recognize his features in the dark.

While speaking of Franklin it may be appropriate for me to read the following short extract from an article which was printed in *Science* a year or two ago in relation to his advanced ideas on light.

"We need not, however, be astonished that he left his impress on the science of his time. A man who, in the middle of the eighteenth century, rejected the doctrine of action at a distance and insisted upon the necessity of a universal medium pervading all space, and who, at the very zenith of Newton's fame, repudiated the corpuscular theory and thought of light as transmitted by a vibratory motion, must be recognized as possessing a mental endowment unequalled by any of the intellects of his time."

You have no doubt observed that all the phosphorescent objects that I have shown continue to shine for quite a long time subsequent to their exposure to the light of the mercury lamp, and this glow would be visible in a dark room for several hours. This is an illustration of "cold light" to which I previously referred. Visible rays are emitted and also some invisible actinic rays, but there are no appreciable heat waves present. Unfortunately, we do not know how to produce this light of sufficient intensity for practical use.

We will now return to the experiment of the disk painted with rhodamin, which exhibits the curious phenomenon of showing a bright pink color under a light which contains only a few feeble red rays.

As before stated, one-half of the face of this disk is covered with copal varnish colored with rhodamin, while the other half is painted over with a solution of rhodamin in plain alcohol. I am indebted to Dr. Steinmetz for the rhodamin and also for information regarding the curious fact that this substance becomes *fluorescent* when dissolved in varnish, but does not exhibit this quality when simply dissolved in alcohol. Thus you will see that under the beams of the mercury arc one-half of the disk appears a bright pink, differing only very slightly from its appearance by incandescent electric light, while the other half presents a completely changed appearance, its former red color being now a bluish black; and yet all the coloring matter used on this disk is identical, and indeed, it all came out of one bottle! The pink color which you see is not the reflection of any visible red rays emitted by the mercury arc, but is a color produced by the inherent property of the rhodamin, which, under certain conditions, absorbs rays of high frequency and then emits them at a lower frequency. The pink color is in fact a purely fluorescent phenomenon.

I have here a phosphorescope which enables us to see the phosphorescent colors of various substances when they are excited by ultra-violet light. This device consists of a cardboard disk mounted on the shaft of an electric motor which rotates at a speed of about 1800 revolutions per minute. On this disk there are three rings of phosphorescent substances laid on in a fine powder. The iron arc is contained in a little chamber which is hinged so that its open end can be directed towards the disk. I will turn on the current a moment before starting the motor and you will see that the preparations on the disk show only fluorescent colors because their phosphorescent colors are masked, or overpowered by the strong visible light of the iron arc.

I will now put the chamber in position so as to shut in the light of the iron arc and then start the motor. You now see the true phosphorescent colors of the different preparations and you will note that they are of remarkable richness and purity. These three colors represent very closely the three primary color sensations of the human eye, which are a full red, a yellowish green, and a bluish violet.

When the exciting rays are turned off, the red phosphorescence of the calcite disappears instantly, while the light of the other two preparations is more persistent. In point of fact, however, the calcite must phosphoresce for a fraction of a second or you would not see any red color on the disk after the calcite has passed outside the influence of the ultra-violet rays.

Beyond the two or more octaves of invisible ultra-violet rays, which are produced by waves in the ether having frequencies of from about 800 to upwards of 3000 billions per second, there exists another wide gap covering seven or eight octaves of unknown radiations, beyond which appear the X-rays of varying intensities, and probably the gamma rays of radium. The X-rays are believed to be manifestations of ethereal pulses having the highest frequency thus far discovered, for of the region beyond them nothing is yet known.

Nearly everybody is now more or less familiar with the wonderful properties of X-rays; how these rays can pass through matter which is absolutely opaque to visible light rays and can then be transformed many octaves down the scale into waves of visible light; and also of their action on the photographic plate, whereby pictures can be made of hidden objects such as the bones in the hand, etc. X-rays are also known to exert a marked effect on living tissue, and cancers and other malignant growths have been pacified if not cured by their application.

Time does not permit me to speak in detail of these truly marvellous radiations which have immortalized the name of their discoverer, Roentgen, so I will conclude with an experiment to illustrate the production of visible light from the invisible X-rays. This experiment is somewhat analogous to previous experiments showing the fluorescent effects of ultra-violet light, with the important difference, however, that we can screen out all visible light from the X-rays by reason of their ability to penetrate opaque substances, whereas it is very difficult to do this with ultra-violet rays, as materials which are opaque to visible light are also more or less opaque to the ultra-violet rays.

I have here a screen on which the word "willemite" is painted with a preparation of that mineral, which becomes luminous when excited by X-rays. The X-ray tube is enclosed in a cardboard box so that no visible light can escape, and you will see that the word shines forth in a pale green color when the tube is put in operation.

We have thus very briefly and superficially traced the radiations produced by ether waves, from the comparatively long Hertzian waves used in wireless telegraphy, through the invisible heat spectrum up to waves producing visible light, thence upwards through the invisible ultra-violet waves and finally into the ethereal pulses which produce X-rays, covering a total range of possibly 40 octaves or more. Out of these we have only been able to study very imperfectly something less than 20 octaves, to say nothing about the regions which exist above and below the limits mentioned, and which are absolutely unexplored; so you will see that we have very much yet to learn about radiation

We may never be able to comprehend the full compass of this vast and magnificent scale of ethereal vibrations, but enough of it has been discovered and understood to sharpen our desires for a broader knowledge and a clearer insight, and just as Maxwell was enabled to predict and Hertz to produce and demonstrate the low frequency electric waves, and as Roentgen was led to discover and make visible the high frequency X-rays, so may other investigators in this infinite field of research be inspired to unfold and bring to light many other manifestations of ethereal activity which are now unknown.

SOME INTERESTING FEATURES ABOUT TUNGSTEN LAMPS

By F. W. Willcox

The tungsten lamp has been on the market now for a little over a year, and over six millions of American made lamps have been sold and placed in service.

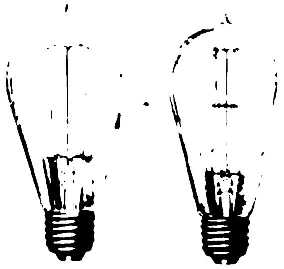
A remarkable manufacturing record has been made by the General Electric Co. in the past year, in the development of this lamp. When it is remembered how many years it took to develop the carbon filament lamp, one cannot fail to be impressed with the results which have been accomplished in one year with the tungsten. In this time, 12 sizes of multiple lamps, 5 sizes of street series lamps, and over 100 varieties of battery miniature tungsten lamps have been produced, with excellent life performances. Innumerable difficulties attending any new development have had to be overcome, in order to make the lamp, with its extremely fine and delicate filament, a practical lamp—one capable of being shipped, handled and used in commercial service with satisfactory results.

The history of the past year and a half would make a very interesting story in itself, and the amount of money which has been spent and is being spent in experimental work, testing the product, and in the devising and building of new and the scrapping of old machinery, would represent a small fortune.

In Fig. 1 the complete line of present tungsten lamps is shown, including the new 25- and 40-watt lamps in the small standard bulbs.

250 Watts 100 Watts 60 Watts 40 Watts

Regular Tungsten Lamps for High Efficiency Units


40 Watts 25 Watts

Regular Tungsten Lamps with Standard Small Bulb

These standard small bulb 25- and 40-watt lamps will fit into the regular installations without any change in the fixtures or shades, and will therefore become a ready substitute for the carbon filament lamps. It is expected that the new 40-watt small bulb lamp will prove very popular, as it enables the central station companies to maintain revenue and give the customer double the amount of light at present given by the standard carbon lamp, at a saving of from 20 to 25 per cent. in energy.

The Company now has four factories engaged exclusively in producing tungsten lamps, and is equipping two more. Their capacities are as follows:

Newark . . .	4,600,000	tungsten lamps per year
East Boston .	2,400,000	" " " "
Toledo	1,600,000	" " " "
Harrison . . .	2,400,000	" " " "
Total . . .	11,000,000	

The tungsten filaments employed in the various sizes of lamps shown above run from 0.001 inch to about 0.0055 inch in diameter. The delicacy of the filament in the 25-watt lamp, which is only 0.001 inch in diameter, is difficult to appreciate; but one can understand how fine this gossamer fibre is when it is stated that the hair of a man's head has a diameter three times as great.

To produce these filaments, diamond dies are employed. The drilling of the holes in these dies requires from two to three weeks steady work, while in many cases the process of making the filaments may wear them out in the course of a day.

Tungsten is principally obtained from ores Wolframite, which is an iron tungstate, and Scheelite, a calcium tungstate. In this country these minerals are found in Colorado, California and Arizona. Wolframite is the more common ore and from this is obtained the dioxide of tungsten, a yellow powder which has been available for a number of years. This powder is reduced to pure tungsten, which is obtained in the form of a very finely divided black powder.

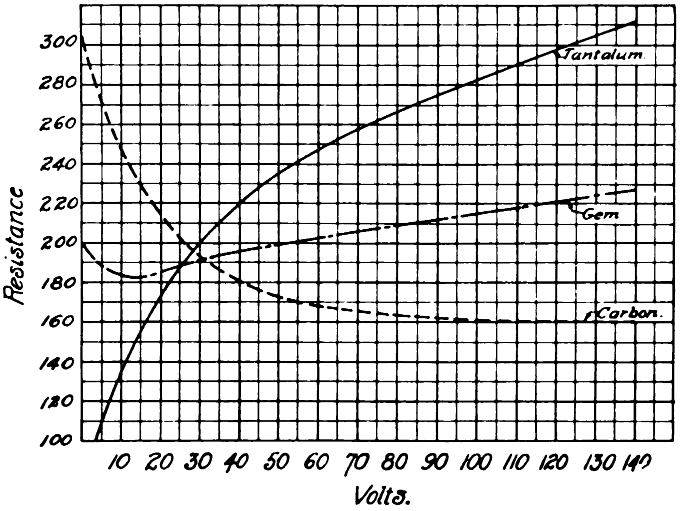


Fig. 2. Change of Resistance with Variation of Temperature (Voltage) of Tantalum, Gem, and Carbon Lamps

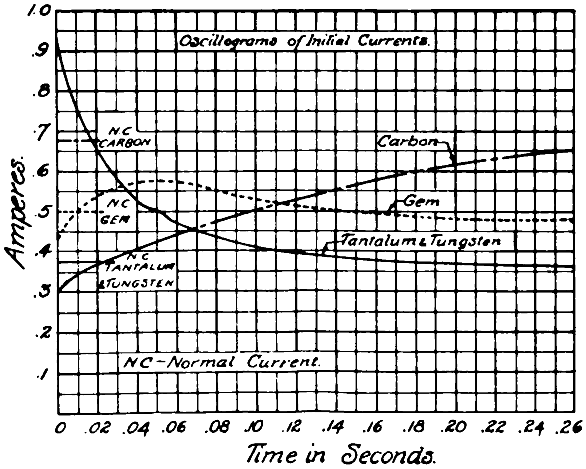


Fig. 3. Oscillograms of Initial Currents of Carbon, Gem and Tungsten Lamps

The tungsten filament is of a slightly gray color and is formed into hair-pin loops of varying lengths, according to the size of the bulb and the candle-power of the lamp.

The general process of mounting the tungsten filament in the bulb and completing the lamp is similar to that employed in the ordinary carbon lamp, except that very much greater care must be taken and more individual hand work employed than is necessary with the carbon lamps.

The supporting stem or mount of the tungsten is different from that of the carbon lamp, consisting of a long glass supporting rod around which the filaments are grouped and supported. In the carbon lamp we have one complete filament, whereas in the tungsten lamp we have four or five filaments, very fine and delicate in character, which must be very carefully threaded through the top anchors

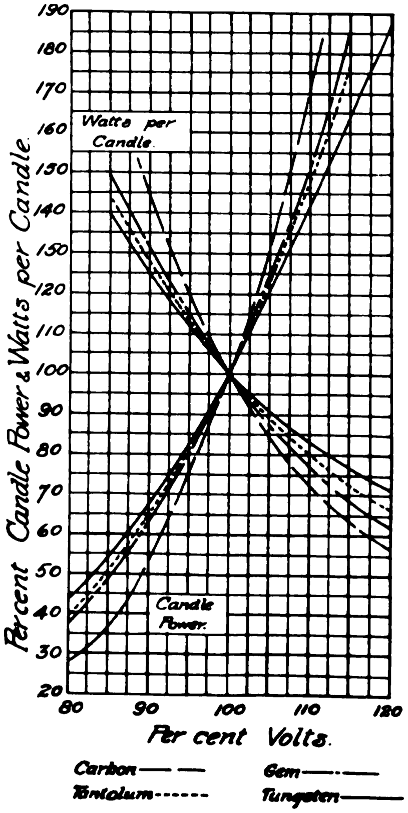


Fig. 4. Variation of Candle-Power and Watts per Candle for Tungsten Lamps with Variation of Voltage

and center supports (where these are used), and brought into position for connection with the leading-in wires. The filament of the carbon lamp is connected to the leading-in wires by a carbon paste. In the case of the tungsten lamp the filament is welded to the connecting wires by hand, by drawing an electric arc between the ends of the filaments and the leading-in wire. In the five-filament lamp there are ten of these electric welds, or ten thousand for every thousand lamps; every one of these welds must be executed with great care by special hand work.

In exhausting the tungsten lamp much more time and effort must be expended than in the case of the carbon lamp.

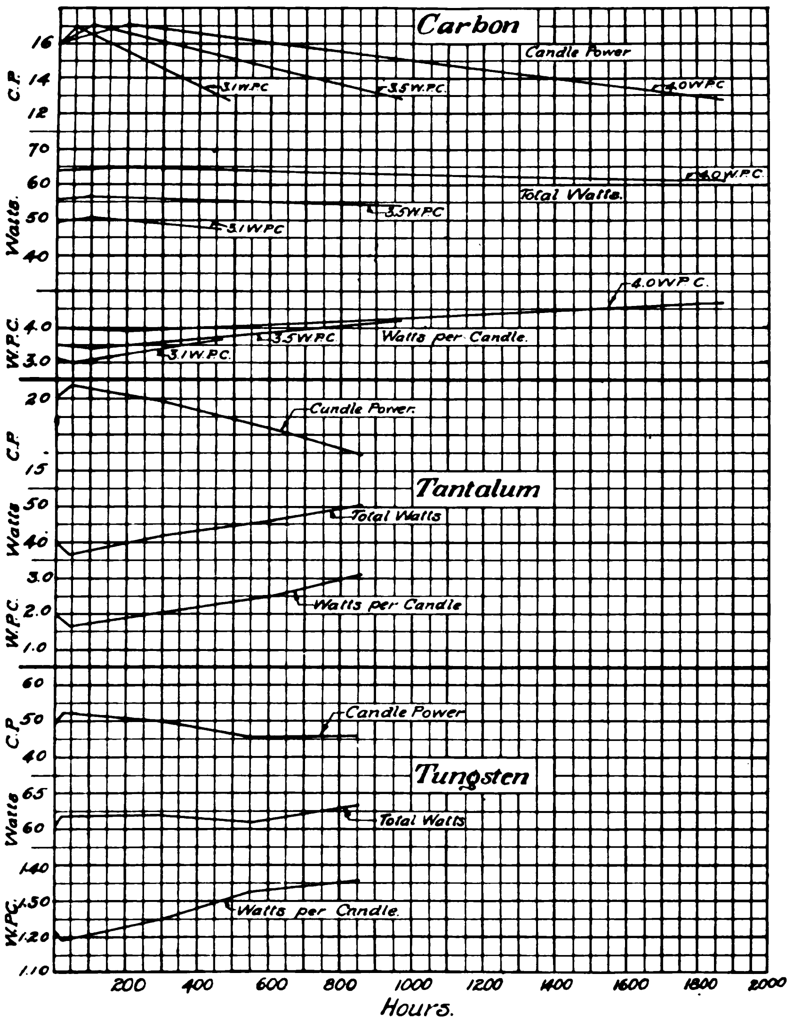


Fig. 5. Variation of Candle-Power, Total Watts, and Watts per Candle during life for Carbon, Tantalum and Tungsten Lamps

Again, in the photometering of tungsten lamps, greater care in handling reduces the speed materially, so that it takes about twice as long for this work as for the photometering of carbon lamps. Carbon lamps are photometered at the candle-power for which they are made and the voltage giving this candle-power is marked on the lamp. Tungsten lamps are photometered at their exact efficiency in watts per candle-power, that is, at 1¼ w.p.c. The candle-power is rated so as to bring the efficiency between the limits of 1.22 and 1.28 watts per candle, and the voltage corresponding is marked on the lamp. The tungsten lamps therefore vary in candle-power and total watts in a given type, but the efficiency is constant. In many respects this method of rating is ideal, as it insures a uniform degree of temperature and strain, and therefore better uniformity in color and brilliancy of the light, and in life of the lamps. All the lamps are rated in total watts, the candle-power in all cases being four-fifths of the rating.

After basing, cleaning and labeling, the lamps are carefully wrapped and packed. The packing methods are much more elaborate than those employed with the carbon lamp. Each lamp is wrapped in cotton wadding which is sealed with a "caution" label, the wrapped lamp being then enclosed in a pasteboard box or carton. These cartons are packed together in compact form and placed in a cushion of excelsior which completely encircles them in the box; the cover of the box being attached with screws. In general, about half the number of tungsten lamps can be packed in the same box space that would be represented by carbon lamps of the same size. The 100-watt lamp requires 3½ times the space of the ordinary carbon lamp.

The following are some interesting facts about tungsten lamps, in comparison with other types of incandescents. The table gives the lengths and diameters, and filament surface of the various lamps:

Filament	Length in Inches	Diam.	Projected Areas Sq. Inches	C.P. per Sq. In. of Projected Area
Carbon 25 c.p.	9.4	.0060	.0564	443
Metallized 20 c.p.	9.5	.0037	.03515	570
Tantalum 20 c.p.	23.4	.0018	.04212	474
Tungsten 80 c.p. 100-Watt	28	.0029	.0812	985

As is well known, the resistance characteristics of metal filaments such as tungsten are the reverse of those of carbon. Fig. 2 shows the curves of resistance and the manner in which this changes with increasing temperature (or voltage) in the different types of filaments.

As a result of this characteristic, there is a very interesting difference in current flow in the different lamps at the moment the current is turned on. This is shown in Fig. 3, which is a reproduction of the oscillograms of the initial current of carbon, Gem and tantalum lamps, as given by Amrine, of the

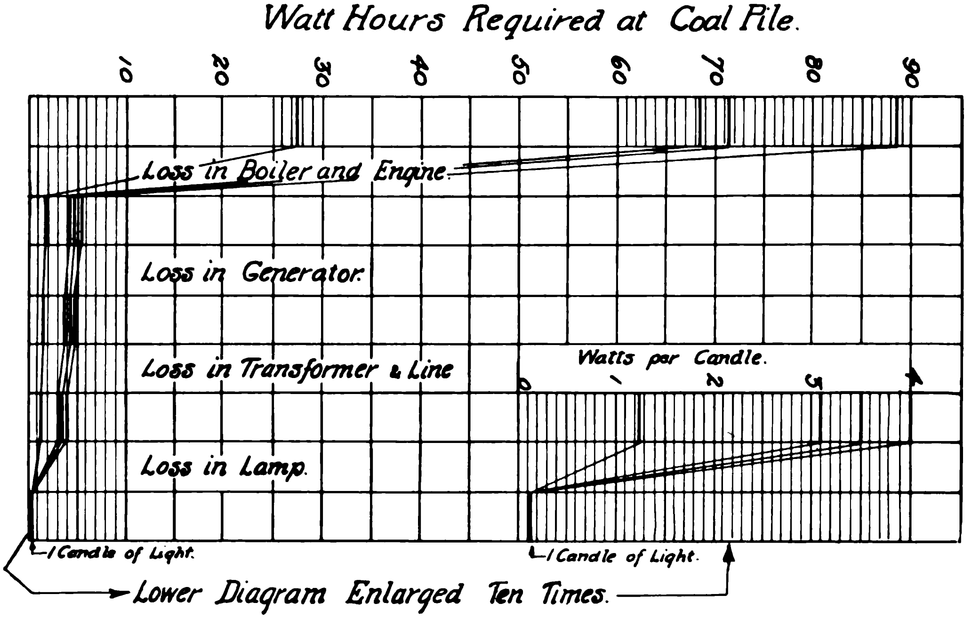


Fig. 6. Diagram Showing in a Relative Way the Losses Between Coal Pile and Lamp. Gives the Energy at Coal Pile Requisite for 1 Candle of Light from Lamp and Shows the Large Saving Effected by Tungsten Lamps Taking 1 1/4 w.p.c. Over Carbon Taking from 3 to 4 w.p.c.

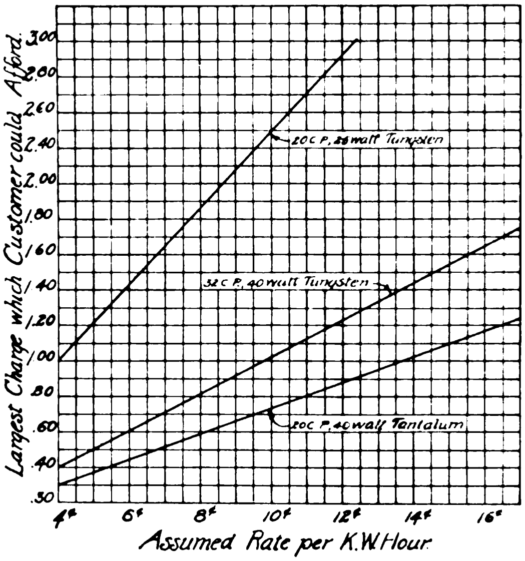


Fig. 7. Largest Price which a Consumer Could Afford to Pay at Various Rates for Tungsten as Compared to Carbon Lamps of Equal Candle-Power Supplied Free

University of Illinois. The curve for tungsten is very similar to that of tantalum.

Table 1 shows the changes in candle-power and efficiency due to change in voltage on the carbon, tantalum, and tungsten lamps, and these results are also given in Fig. 4.

The relative life and candle-power performance of the different lamps, that is, the change in candle power during life and also the change in total watts and efficiency (watts per candle-power), are given in Fig. 5. These curves show the remarkably long life obtained with tungsten lamps, exceeding all but that of the low efficiency types of carbon lamps.

TABLE I

Change of Candle-Power and Efficiency due to Change of Voltage, for Carbon, Gem, Tantalum and Tungsten Lamps

	CARBON			GEM			TANTALUM			TUNGSTEN		
	% V.	% C.P.	%W P.C.	% V.	% C.P.	%W.P C.	% V.	% C.P.	%W P.C	% V.	% C.P.	%W.P.C:
Under Voltage	80	28		80	36		80	39		80	43	
	85	36		85	47.3		85	49.3	144.5	85	53.1	140.3
	90	52.3	145	90	62	131.8	90	64	128	90	67	126
	92.5	62.6	132	92.5	70.2	123.7	92.5	72	120.5	92.5	75	118.9
	95	76	120	95	79.6	115.5	95	80.7	113.4	95	82.9	112
	97.5	87.1	109.6	97.5	89.1	107.5	97.5	89.7	107	97.5	91.2	106.5
	100	100	100	100	100	100	100	100	100	100	100	100
Over Voltage	102.5	115	91.8	102.5	112	93.5	102.5	111.3	94	102.5	110	95.4
	105	130.5	84.3	105	124.1	87.5	105	122.8	89.2	105	120	91.7
	107.5	149	77.2	107.5	138	82.3	107.5	135	84.6	107.5	130.4	86.8
	110	169.2	71.5	110	152.7	77.3	110	148	80.1	110	141.6	82.9
	115		63	115	185.5	68.2	115	177.7	74.3	115	164	76.2
	120		56.4	120		61.6	120		66	120	188	71

As is well known, the absolute efficiency of the ordinary lamp as a producer of light is very low; but this is also true of all other forms of artificial light. Excepting the arc light, the ordinary carbon incandescent lamp has a better efficiency than other lamps, averaging about 3.5 per cent. of light giving efficiency. This means that 96.5 per cent. of the energy is wasted in heat and non-luminous vibrations, and only 3.5 per cent. given out as light, or luminous vibrations.

This absolute efficiency has been increased in the case of the new tungsten lamp to about 8 per cent. This is quite a material gain, considering the efficiency of the lamp as placed at the peak of a pyramid, the base of which represents the original source of energy —the coal pile. As an illustration, Fig. 6 shows, in a relative way, the loss from the coal pile to the lamp and the material reduction in the base of the pyramid, that is, the reduced amount of coal required for a given amount of light, as compared with the ordinary carbon lamp.

The General Electric bulletin No. 4646 on the tungsten lamp gives some interesting tables and diagrams showing the economy of the tungsten as compared to the carbon lamp; some additional comparison tables and diagrams showing the superior economy of the former lamp are here given.

In Table 2 is shown the hours of life required to save the full list price cost of the tungsten lamp over an equal candle-power and length of service of carbon lamps, at a rate of 10 cts. per kw-hr.

In Table 3 is shown the price which customers could afford to pay for the various tungsten lamps in cases where carbon lamps are furnished on the free renewal basis. This result is also diagrammed in Fig. 7.

In Fig. 8 is shown a diagram of the number of hours' use obtainable for a given annual cost, for the 32 c.p. carbon and the 32 c.p. tungsten lamps.

In Table 4 is given the minimum rate for current per kilowatt-hour at which the various lamps pay their full cost.

In Fig. 9 is shown the relative cost of producing a candle-power of light with the various lamps on the differential cost basis; that is, the fixed charges which are independent of the hours' use, plus the running charges which vary with the hours' use. This table shows that with the tungsten 100-watt lamp a generating station can produce light at about one-half of what it would cost with the 16 c.p., 3.1 w.p.c. lamp. This is a striking example, as the value includes the heavy renewal costs of the tungsten lamps, and shows that, in spite of the higher first cost of the tungsten, its economy is sufficient to halve the actual cost of light production, considering the interest on the necessary plant investment required.

This is a perfectly true comparison for a company generating light for its own purposes; as, for example, an isolated plant, basing its cost on the necessary investment for a new plant to furnish an equal amount of illumination with tungsten or with carbon lamps.

Unfortunately, as far as central station

TABLE II

Tungsten vs. Carbon Lamps. Hours of Life to save full list cost of tungsten lamp at 10 cents per kilowatt-hour.

	20 c.p.	32 c.p.	48 c.p.	80 c.p.	200 c.p.
Carbon lamps consume in watts .	62	100	150	250	620
Tungsten lamps consume in watts .	25	40	60	100	250
Watts saved by tungsten . . .	37	60	90	150	370
Value of saving per hour at 10 cents per kilowatt-hour . .	$0.0037	$0 006	$0.009	$0.015	$0.037
List cost of tungsten lamp . .	$0.85	$1.10	$1.40	$1.75	$3.50
Hours life to re-pay cost of tungsten	230	183	155	116	94.6

It will be noted that for 800 hours life assumed for the tungsten, the following is true:

25 watt tungsten saves its first cost 3 times over.
40 " " " " " " 4.4 " "
60 " " " " " " 5 " "
100 " " " " " " 7 " "
250 " " " " " " 8 " "

TABLE III

Central station charge for the various types of lamps which customer could pay without loss, assuming in each case that the carbon lamps are furnished on the free renewal basis.

Type of Lamp	Assumed Rate Per Kw. Hr.	Assuming That One Tungsten Lamp Replaces Each 16 c.p. Carbon Lamp	Assuming That One Tungsten Lamp Replaces Each 32 c.p. Carbon Lamp	Assuming That Enough Tungsten Lamps Are Used to Furnish Equal c.p. as 16 c.p. Carbon Lamps
20 c.p. 25 watt Tungsten	5 cts.	$1.25		$1.85
	7½ "	1.875		2.775
	10 "	2.50		3.70
	15 "	3.75		5.55
32 c.p. 40 watt Tungsten	5 cts.	0 50	$3.00	3.00
	7½ "	0.75	4.50	4.50
	10 "	1.00	6.00	6.00
	15 "	1.50	9.00	9.00
48 c.p. 60 watt Tungsten	5 cts.		2.00	4.50
	7½ "		3.00	7.00
	10 "		4.00	9.00
	15		6.00	13.50
80 c.p. 100 watt Tungsten	5 cts.			7.50
	7½ "			11.25
	10 "			15.50
	15 "			22.50

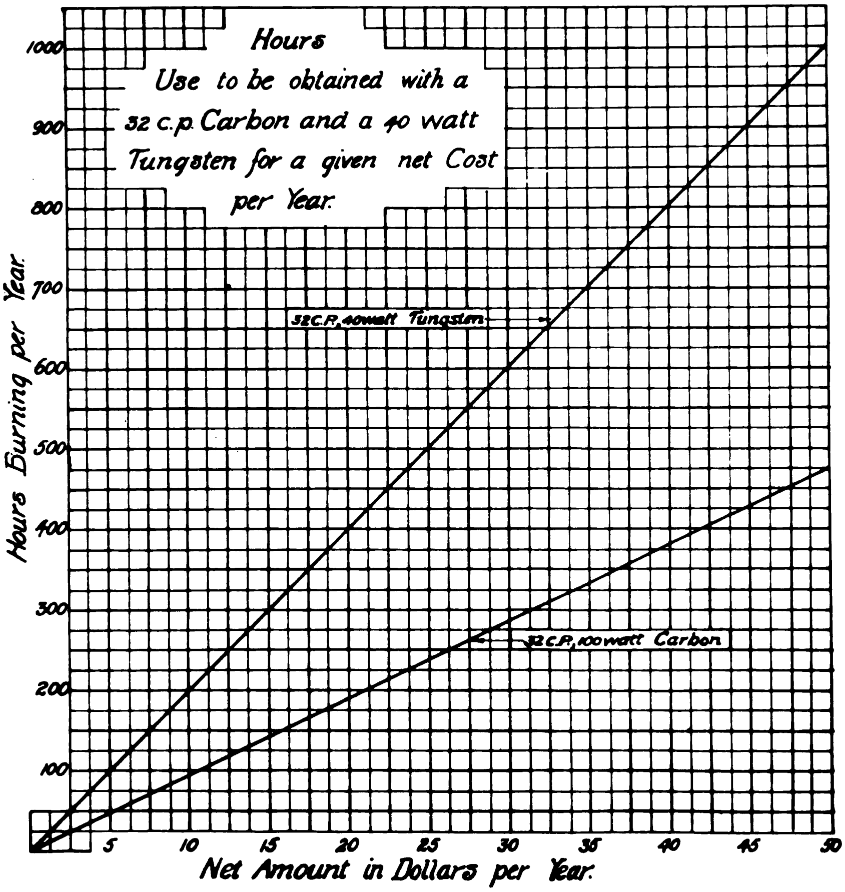


Fig. 8. Hours use obtainable for a given annual expenditure from Carbon and Tungsten 32 candle lamps

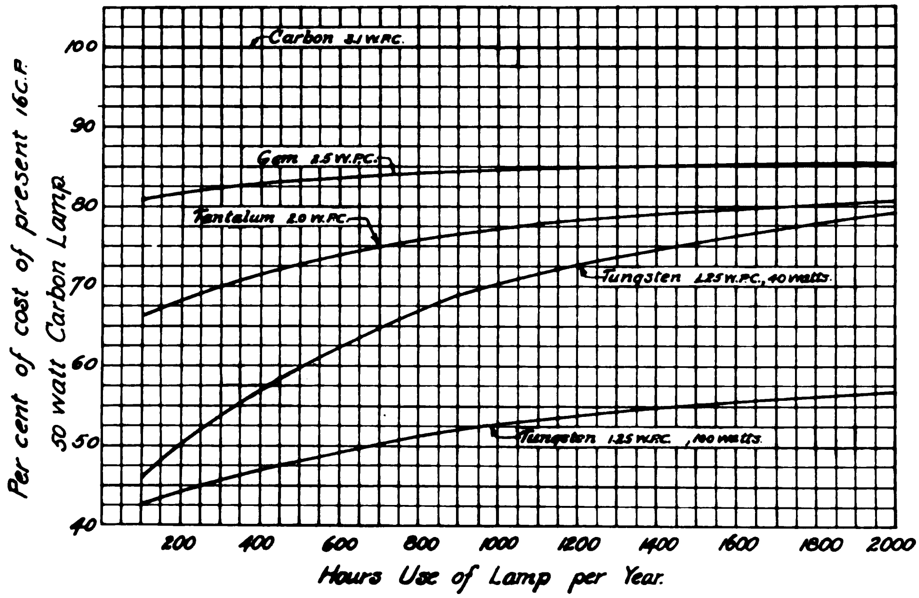


Fig. 9. Relative cost of producing a candle hour of light with various electric lamps, estimated on the differential cost basis for various hours use of lamp per year

service is concerned, the light produced is not sold on the light basis, but on the energy, or kilowatt-hour basis, and therefore the central station receives no such direct benefit from the higher economy of the tungsten multiple lamp as it does from the street series tungsten lamp. In the latter case, the central station receives pay on the basis of the illumination, or light given, the charge being by the lamp year. The higher economy of the series tungsten lamp therefore gives a direct gain to the central stations using them.

Tungsten series lamps have been a marked success and are widely used. Practically 90 per cent. of the street series lamps we are now supplying are of the tungsten type, and it is expected that the manufacture of all other types of street series incandescent lamps, such as the carbon and Gem, will be discontinued, and such lamps rendered obsolete.

The breakage record of tungsten lamps has shown a materially improved result, and at present compares very favorably with the carbon lamps, not exceeding 1 to 1½ per cent. A large part of the tungsten shipments are made by freight, and it has been found that the lamps carry better in many cases this way than by express. In ordinary cases this would be the preferred method of shipment for tungsten lamps.

The breakage on tungsten lamps in handling, and in service in central stations and by consumers, has also been greatly reduced as the result of greater care. Table 5 gives some interesting information obtained from one of the large eastern illuminating companies, showing that the total breakage, including shipping, handling and early burnouts, amounts to 6 per cent. on the average.

The tungsten lamp is also creating a revolution in the field of small lamps for battery service, for flash lights, automobile lights, etc.; but a separate chapter should be written about these.

TABLE IV

Comparison of Carbon, Tantalum and Tungsten Lamps and Service at Minimum General Prices

	Carbon 50 W. 16 C.P.	Tantalum 40 W.	TUNGSTEN				
			40 W.	40 W.	60 W.	100 W.	250 W.
Assumed Life	500	800	800	800	800	800	800
List Price—20, 15 and 10% Dis.	$0.136	$0.34	$0.52	$0.673	$0.8568	$1.071	$2.142
Kw. hours during life	25	32	20	32	48	80	200
Cost of renewals per kw.-hour	.55c.	1.06c.	2.6c.	2.1c.	1.79c.	1.34c.	1.07c.
Candle hours during life	7350	14,720	15,000	23,680	35,580	60,000	150,000
Cost of power per 100 candle hours @ 10c. per kw.-hour	3.4c.	2.17c.	1.33c.	1.33c.	1.33c.	1.33c.	1.33c.
Cost of renewals per 100 c.p. hours	.185c.	.231c.	.347c.	.284c.	.241c.	.179c.	.143c.
Total cost of power and lamp renewals per 100 c.p. hours	3.585c.	2.401c.	1.677c.	1.614c.	1.571c.	1.509c.	1.473c.
Cost of power per 100 hours of service @ 10c. per kw.-hour	50c.	40c.	25c.	40c.	60c.	$1.00	$2.50
Total cost of power and lamp renewals per 100 hours of service	52.72c.	44.25c.	31.50c.	48.42c.	70.71c.	$1.134	$2.768

TABLE V

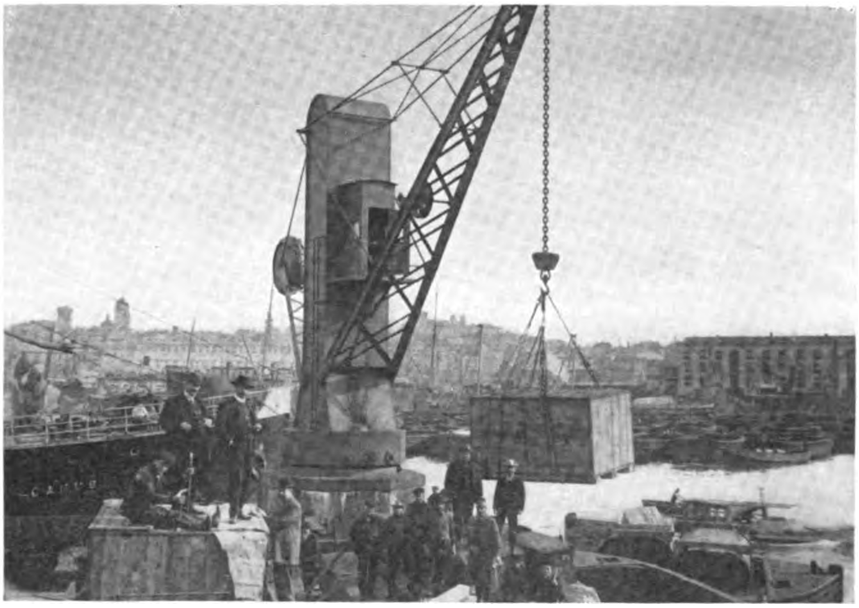
Tungsten Lamp Breakage Record of a Leading Eastern Central Station Company

Size of Lamp	100 WATT		60 WATT		40 WATT		25 WATT		TOTAL	
	No.	%	No.	%	No.	%	No.	%	No.	%
Lamps used	14691		9888		11392		24218		59106	
Breakage	595	4	507	5.1	941	8.3	426	1.8	2469	4.2
Early burnout	390	2.6	111	1.1	242	2.1	416	1.7	1159	2
Total breakage	985	6.6	618	6.2	1183	10.4	842	3.5	3628	6.2

FOREIGN SHIPPING ROUTINE

By E. F. Colyer

It is quite generally understood that in the shipment of merchandise to foreign countries there are certain formalities to be observed which are entirely unnecessary with domestic shipments, although there seems to be a widespread impression that these requirements are due to certain arbitrary regulations of foreign customs authorities, which could very easily be dispensed with if the authorities were disposed to be obliging. Not a few shippers act on the assumption that where this obliging disposition is not displayed, moral suasion should be brought to bear by ignoring the regulations entirely, and feel peculiarly hurt when their inattention to the rules results in aggravated delays, increased expenses, and even heavy fines, which the consignee may consider himself justified in billing back against them.



Unloading 2700 kw. Transformers at Genoa. Case Being Opened on Wharf for Examination by Customs Officials

The Foreign Department of the General Electric Company, in order that it may be fully equipped to properly take care of the details of its shipments, maintains at New York a special shipping office to receive and forward all goods exported through that port. To the staff of this office is entrusted the responsibility for the booking of freight, its delivery to the steamer, the preparation and mailing of all shipping documents, and the general compliance with the customs' regulations, not only of the various foreign countries to which shipments are made, but those of the United States as well. Just what this involves may be better understood by a brief analysis of some of the conditions governing commercial transactions between different countries.

When forwarding goods to any domestic point, the shipper ordinarily has at his command one or more railroads or express companies, ready at all times to receive freight, and, provided the shipment is properly marked, to carry it to its destination with reasonable despatch. Unless consigned to order, the consignee is usually not obliged to present a railroad bill of lading or express receipt, and goods are delivered by the carrier if consignee is known to its agent. For foreign shipments the exporter has no carrier who is prepared to accept freight without previous advice, and to forward immediately. Nor will the carrier deliver to consignee without proper evidence of ownership, by the presentation of signed bills of lading.

Instead of a frequent train service he must depend on an infrequent, and often very irregular steamer service. Owing to the high cost of wharf space the steamship companies cannot hold freight on dock, and will not agree to accept it except when steamers are loading. Where the service to any country may be taken care of by several lines jointly, which load boats in succession and at different piers, it is evident that much inconvenience would be caused were the steamship lines to accept cargo without restricting themselves to the carrying capacity of the ship then loading. To guard against the delivery of an excess of freight to any vessel, and also to guide the dock superintendents in loading steamers, it is customary for the steamship agent to issue to intending shippers delivery "permits" for specified quantities of cargo, and these permits must be lodged with the receiving clerk for the ship before the freight covered by same will be accepted. Occasionally a steamer is overbooked by mistake and cargo already receipted for is shut out—a most disagreeable and unsatisfactory state of affairs, which is generally discovered but an hour or two prior to the sailing of the steamer. In such an event all shipping documents have to be hastily rewritten and all possible steps taken to minimize the trouble to the consignee.

Again, in making a domestic shipment the transaction has until recently been considered as concerning only the shipper, the carrier and the consignee. Since the National and State Governments have assumed active oversight of common carriers and have imposed on shippers the burden of more fully posting themselves on freight rates to avoid difficulties arising from inadvertently accepting less than the published tariff, the Government's interest in shipments is more evident to the domestic shipper. Still, this interest is as nothing compared with the watchfulness with which export and import shipments are regarded. The Government does not concern itself with ocean freight rates, and these, within certain limits, remain a matter of bargaining between shipper and carrier; but a complete record of shipments is kept at the points where they leave the country, the information being required for various purposes, statistical and otherwise. To enable the Government to make such a record, every shipper is required to file through the medium of the transportation company a certified statement of the character and value of each export shipment made by him. This is the "shipper's manifest," required by all railroads and express companies on goods exported by rail, or the "partial manifest," otherwise known as a "clearance," demanded by steamship lines. On every rail shipment consigned on a through railroad bill of lading to any point beyond the United States, a shipper's manifest of goods exported must be handed to the local railroad agent, unless consigned in care of some agent at the port of departure, in which latter case full information must be supplied to such agent to enable him to prepare a clearance. The manifests or clearances form a part of the documents filed by the transportation companies with the customs authorities at the exporting point, and are used to verify any re-entry of the goods for repair or the like, and to guard against the free importation of foreign goods under the claim that they are of American make.

Any country depending on a tariff on imports for a large share of its revenues, or to protect home industries against foreign manufactures, must necessarily provide a more or less elaborate machinery to enable it to collect the duties imposed. The higher the tariff the greater the incentive to get around it, and therefore the greater the need for careful watching of all entries. Some countries, including the United States, require invoices to be certified to before their respective consuls, or that special consular invoices be prepared, or that the bills of lading be certified to. The fees for such certification may be nominal, or they may be a substantial percentage on the value of the goods and go far toward paying the cost of the consular service. The consul fee on shipments to Mexico, for instance, averages about one fourth of one per cent. on invoices in excess of $50.00 in value: below that amount there is no charge. As the sales from the United States to Mexico are of a total value of some fifty to sixty million dollars yearly, the annual fees on such shipments must therefore aggregate upwards of $125,000. The United States does not require consular invoices where goods are of a less value than $100.00, but demands such invoices on all shipments of greater value, apparently with the idea that where large shipments are being made the consul may be in position to detect under-billing. It is interesting to note that European countries generally, not excepting Russia, do not complicate their foreign commercial relations by asking that shippers present documents of any kind to their consuls abroad for verification—nor does Japan. In this feature of international trade the United States follows the practice of the Latin American countries rather than that of other great commercial nations.

It should not be assumed, however, that because no consular documents may be required, other shipping papers can be dispensed with. Even in free-trade England there are a few articles—tobacco, spirits, sugar, tea, and one or two others—on which an import tax is placed, and the clearing of shipments through the custom house is naturally greatly facilitated by the presentation of invoices or shipping lists showing that nothing dutiable is comprised in a shipment, or if there are any dutiable items, the quantity and value of each. Without such documents each package must be examined, which examination takes time and also costs money, and the owner of the goods pays the bill. Within the past three or four years the English customs authorities have become more particular in obtaining for statistical purposes exact values of all imported goods, and invoices are now necessary where packing lists were at one time sufficient. This being the situation with a free trade country, it is not difficult to appreciate that where duties must be collected on practically everything imported the clearing through customs may be much expedited by the prompt presentation to the authorities of full details of shipments.

It is not customary to open every package for customs examination. In the United States one or two cases, and on large shipments, five per cent of the shipment is generally held back by the authorities for inspection and to verify the entry made by the importer. When the duty is deposited on the entire shipment, the bulk of the shipment is passed without examination and without loss of time, the cases withheld being released after examination. Duties must be paid in cash, any excess collected being refunded to the importer after the entry has been carefully checked and the rates assessed have been verified or corrected. The prices shown on consular invoice are generally used as a basis for determining the amount to be collected on all goods on which duty is payable as a certain percentage of its value (*ad valorem*). A higher price may be fixed

Tank for 2700 kw. Transformer Showing Force Employed at Genoa for Unloading, Checking and Passing Through Customs.

by the appraiser if he is not satisfied with the values shown in the consular invoice, but never a lower price. If goods are underbilled either a fine, in the shape of an additional percentage of duty on the underbilling, or confiscation of the shipment may result. If any importer is dissatisfied with the appraisement on an entry made by him he may appeal to the Treasury Department for relief—and sometimes get it.

There are many ways of fixing duties. They may be based on the weight, measurement, or value of goods, or may be a combination of these methods. Different grades of the same class of goods may pay duties at different rates per pound, or at different rates per square foot, or even at different percentages on the value. When paid on weight, duties may be assessed on net weight, gross weight, or legal weight, the latter being the weight of goods plus the weight of the glass, tin, or cardboard retainers, but excluding the outer case. To give incorrect weights where duties are paid on a weight basis is likely to prove as serious as to bill incorrectly when duties are payable *ad valorem.*

When a number of items are packed together in the same case, as is quite a common occurrence with the miscellaneous supply material going to make up the equipment of an electrical plant, care must be taken, as a rule, to give detailed values or weights of the different classes in any one case, otherwise duty may be assessed on the entire case at the rate payable on the item carrying the highest rate. Some countries require that the papers presented at their customs house shall be complete in this respect, and do not give the importer much leeway in correcting or verifying the information supplied by the shipper when entry is made.

Even though the apparent unwillingness to facilitate importations may be aggravating, expensive, and to the shipper seem unnecessarily harsh, it must be borne in mind that the conditions are often peculiar, and the character of the assistance available not such as to make the job of collector of the port a particularly easy one. If it is required that marks shall be stencilled and shall appear plainly on two or more sides of the case: that cases shall be consecutively numbered and no other marks or numbers than the shipping marks shall appear on the packages; and that the marks and numbers on the shipping documents shall agree exactly with those shown on the packages; these requirements have been fixed because they have been found absolutely essential to the speedy checking and clearing of shipments. Where brush marking is permitted some of it is bound to be pretty bad, as has been found from experience, and by the time the packages have gone through a long voyage and have been rubbed and chafed against other shipments such marks are frequently illegible, especially when a lot of miscellaneous information is also daubed all over the cases. Where legibly stencilled marks are given, and on two sides of the case, much needless handling is avoided, as the marks can be easily seen and the goods readily stacked for checking. On foreign shipments it is now the practice of the General Electric Company to stencil all marks, using for the purpose a machine which cuts out paper stencils and works on the same principle as the small machines used for perforating bank checks. The letter made with this machine is not as large as would be desirable, but the marks are much clearer than when written by hand, and the legibility of the shipping marks is further increased by the use of case numbers two inches or more in height.

The stipulation made by some countries that consular invoices shall be in the language used by them is not unreasonable. To properly pass on the documents presented, the authorities must be able to understand what they cover, and when consular invoices in English are permitted on shipments to a Spanish speaking country, these invoices must pass through the hands of the official translators before the appraisers are in a position to act. In such cases clearing of shipments is very greatly expedited by the preparation of Spanish invoices at the shipping point. It is only natural that custom house clerks should select for immediate attention, from the papers presented to them, those which are complete and require the least work on their part, and that they should set aside for a more convenient time the entries that are involved, or are in unsatisfactory shape. Conditions in this respect are alike all over the world, and goods may be delayed quite as long in New York City as in Timaru, due to incomplete or incorrect shipping papers.

Some shippers consider it desirable to have marked on the outside of the cases what they contain. This is not always advisable, for other reasons than rendering the shipping marks less distinct. On the west coast of South America thieving is reduced to a science. In a report made some months ago by a representative of a marine underwriter, the statement is made that in one country thousands of people live by theft alone, and there are businesses where only stolen goods are handled. If the contents of valuable cases are indicated on the packages, the attention of these gentry is directed to them, and all or part of the goods may be abstracted. Incandescent lamps seem to be their specialty in the electrical line.

In order to meet the conditions which have been briefly touched on above, general instructions are issued to the various factories of the General Electric Company and to manufacturers from whom material may be purchased for foreign shipment, detailing certain broad requirements which it is necessary to follow on all foreign shipments, no matter what the destination. Furthermore, special instructions are issued by the Foreign Department covering the points peculiar to any particular country. Added to these, the customer may have some directions of his own which must be followed, as they generally refer to some condition which would otherwise not receive attention. It may be that occasional shipments can be handled without all of these instructions being complied with; but all shipments cannot, and it is much simpler to give at times a little more information than is absolutely necessary, if by so doing it is made certain that enough information is given to enable the consignee to promptly clear his goods. By shipping practically all foreign material to its New York office for reforwarding, the Foreign Department is enabled to detect and remedy prior to shipment from the country any deficiencies in the information supplied, and to ensure that its shipping documents shall be complete, in proper order, and mailed in season to reach the customer as soon as the goods themselves arrive at the port of entry, this last, as has been seen, being imperative.

It is a somewhat curious fact that, in returning goods for repair or for other reasons, those who are most insistent on the careful observance of their own shipping instructions frequently disregard entirely the requirements governing the re-entry of such material. A very large proportion of such returns are made either unaccompanied by documents of any kind, or with the papers that are supplied lacking in important particulars. Instances are not uncommon where material has lain in bonded warehouse for months, accumulating storage charges because no documents had been furnished and the shipment could not be identified. On all returned goods valued at more than one hundred dollars a "certificate of American goods returned," made out on forms to be obtained from any American consul, must be furnished, duly attested by the consul. On shipments of less value this certificate is not needed, but on every return full information should be given so that the outward shipment of the material may be proven by a reference to the original custom house entry. All papers must be presented to the customs authorities within forty-eight hours after the arrival of steamers, otherwise goods are "general ordered" into bonded warehouse, and cartage and storage charges accrue. Further delays in clearing shipments are also likely to occur on goods "general ordered" when papers are finally presented, which, on rush repair jobs, would preferably be avoided.

TABLE I

TRANSMISSION LINE CONSTANTS *

SELF-INDUCTION

$L = \left(0.141 \log \frac{D}{d} + 0.0576\right)$ Millihenries

SOLID CONDUCTORS

Millihenries per 1000 Feet of Conductor (For One Wire)

Interaxial Distance, Inches	SIZE OF WIRE																		
	0000	000	00	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
3/8	...	...	.0591	.0662	.0733	.0803	.0874	.0944	.1015	.1085	.1156	.1226	.1297	.1367	.1438	.1508	.1579	.1649	.1720
1/2	.0625	.0696	.0766	.0837	.0908	.0978	.1049	.1119	.1190	.1260	.1331	.1401	.1472	.1542	.1613	.1683	.1754	.1824	.1895
3/4	.0871	.0942	.1012	.1083	.1154	.1224	.1295	.1365	.1436	.1506	.1577	.1647	.1418	.1788	.1859	.1929	.2000	.2070	.2141
1	.1046	.1117	.1187	.1258	.1329	.1399	.1470	.1540	.1611	.1681	.1752	.1822	.1893	.1963	.2034	.2104	.2175	.2245	.2316
2	.1467	.1538	.1608	.1679	.1750	.1820	.1891	.1961	.2032	.2102	.2173	.2243	.2314	.2384	.2455	.2525	.2596	.2666	.2737
3	.1713	.1784	.1854	.1925	.1996	.2066	.2137	.2207	.2278	.2348	.2419	.2489	.2560	.2630	.2701	.2771	.2842	.2912	.2983
4	.1889	.1960	.2030	.2101	.2172	.2242	.2313	.2383	.2454	.2524	.2595	.2665	.2736	.2806	.2877	.2947	.3018	.3088	.3159
5	.2025	.2096	.2166	.2237	.2308	.2378	.2449	.2519	.2590	.2660	.2731	.2801	.2872	.2942	.3013	.3083	.3154	.3224	.3295
6	.2135	.2206	.2276	.2347	.2418	.2488	.2559	.2629	.2700	.2770	.2841	.2911	.2982	.3052	.3123	.3193	.3264	.3334	.3405
7	.2229	.2300	.2370	.2441	.2512	.2582	.2653	.2723	.2794	.2864	.2935	.3005	.3076	.3146	.3217	.3287	.3358	.3428	.3499
8	.2310	.2381	.2451	.2522	.2593	.2663	.2734	.2804	.2875	.2945	.3016	.3086	.3157	.3227	.3298	.3368	.3439	.3509	.3580
9	.2382	.2453	.2523	.2594	.2665	.2735	.2806	.2876	.2947	.3017	.3088	.3158	.3229	.3299	.3370	.3440	.3511	.3581	.3652
10	.2446	.2517	.2587	.2658	.2729	.2799	.2870	.2940	.3011	.3081	.3152	.3222	.3293	.3363	.3434	.3504	.3575	.3645	.3716
11	.2504	.2575	.2645	.2716	.2787	.2857	.2928	.2998	.3069	.3139	.3210	.3280	.3351	.3421	.3492	.3562	.3633	.3703	.3774
12	.2556	.2627	.2697	.2768	.2839	.2909	.2980	.3050	.3121	.3191	.3262	.3332	.3403	.3473	.3544	.3614	.3685	.3755	.3826
15	.2693	.2764	.2834	.2905	.2976	.3046	.3117	.3187	.3258	.3328	.3399	.3469	.3540	.3610	.3681	.3751	.3822	.3892	.3963
18	.2803	.2874	.2944	.3015	.3086	.3156	.3227	.3297	.3368	.3438	.3509	.3579	.3650	.3720	.3791	.3861	.3932	.4002	.4073
21	.2897	.2968	.3038	.3109	.3180	.3250	.3321	.3391	.3462	.3532	.3603	.3673	.3744	.3814	.3885	.3955	.4026	.4096	.4167
24	.2978	.2949	.3119	.3190	.3261	.3331	.3402	.3472	.3543	.3613	.3684	.3754	.3825	.3895	.3966	.4036	.4107	.4177	.4248
30	.3114	.3185	.3255	.3326	.3397	.3467	3538	.3608	.3679	.3749	.3820	.3890	.3961	.4031	.4102	.4172	.4243	.4313	.4384
36	.3224	.3295	.3365	.3436	.3507	.3577	.3648	.3718	.3789	.3859	.3930	.4000	.4071	.4141	.4212	.4282	.4353	.4423	.4494
42	.3319	.3390	.3460	.3531	.3602	.3672	.3743	.3813	.3884	.3954	.4025	.4095	.4166	.4236	.4307	.4377	.4448	.4518	.4589
48	.3399	.3470	.3540	.3611	.3682	.3752	.3823	.3893	.3964	.4034	.4105	.4175	.4246	.4316	.4387	.4457	.4528	.4598	.4669
54	.3471	.3542	.3612	.3683	.3754	.3824	.3895	.3965	.4036	.4106	.4177	.4247	.4318	.4388	.4459	.4529	.4600	.4670	.4741
60	.3535	.3606	.3676	.3747	.3818	.3888	.3959	.4029	.4100	.4170	.4241	.4311	.4382	.4452	.4523	.4593	.4664	.4734	.4805
66	.3593	.3664	.3734	.3805	.3876	.3946	.4017	.4087	.4158	.4228	.4299	.4369	.4440	.4510	.4581	.4651	.4722	.4792	.4863
72	.3646	.3717	.3787	.3858	3929	.3999	.4070	.4140	.4211	.4281	.4352	.4422	.4493	.4563	.4634	.4704	.4775	.4845	.4916
78	.3695	.3766	.3836	.3907	.3978	.4048	.4119	.4189	.4260	.4330	.4401	.4471	.4542	.4612	.4683	.4753	.4824	.4894	.4965
84	.3740	.3811	.3881	.3952	.4023	.4093	.4164	.4234	.4305	.4375	.4446	.4516	.4587	.4657	.4728	.4798	.4869	.4939	.5010
90	.3782	.3853	.3923	.3994	.4065	.4135	.4206	.4276	.4347	.4417	.4488	.4558	.4629	.4699	.4770	.4840	.4911	.4981	.5052
96	.3821	.3892	.3962	.4033	.4104	.4174	.4245	.4315	.4386	.4456	.4527	.4597	.4668	.4738	.4809	.4879	.4950	.5020	.5091
102	.3858	.3929	.3999	.4070	.4141	.4211	.4282	.4352	.4423	.4493	.4564	.4634	.4705	.4775	.4846	.4916	.4987	.5057	.5128
108	.3893	.3964	.4034	.4105	.4176	.4246	.4317	.4387	.4458	.4528	.4599	.4669	.4740	.4810	.4881	.4951	.5022	.5092	.5163
114	.3926	.3997	.4067	.4138	.4209	.4279	4350	.4420	.4491	.4561	.4632	.4702	.4773	.4843	.4914	.4984	.5055	.5125	.5196
120	.3957	.4028	.4098	.4169	.4240	.4310	.4381	.4451	.4522	.4592	.4663	.4733	.4804	.4874	.4945	.5015	.5086	.5156	.5227
126	.3986	.4057	.4127	.4198	.4269	.4339	.4410	.4480	.4551	.4621	.4692	.4762	.4833	.4903	.4974	.5044	.5115	.5185	.5256
132	.4014	.4085	.4155	.4226	.4297	.4367	.4438	.4508	.4579	.4649	.4720	.4790	.4861	.4931	.5002	.5072	.5143	.5213	.5284
138	.4041	.4112	.4182	.4253	.4324	.4394	.4465	.4535	.4606	.4676	.4747	.4817	.4888	.4958	.5029	.5099	.5170	.5240	.5311
144	.4067	.4138	.4208	.4279	.4350	.4420	.4491	.4561	.4632	.4702	.4773	.4843	.4914	.4984	.5055	.5125	.5196	.5266	.5337
150	.4092	.4163	.4233	.4304	.4375	.4445	.4516	.4586	.4657	.4727	.4798	.4868	.4939	.5009	.5080	.5150	.5221	.5291	.5362
156	.4116	.4187	.4257	.4328	.4399	.4469	.4540	.4610	.4681	.4751	.4822	.4892	.4963	.5033	.5104	.5174	.5245	.5315	.5386
162	.4139	.4210	.4280	.4351	.4422	.4492	.4563	.4633	.4704	.4774	.4845	.4915	.4986	.5056	.5127	.5197	.5268	.5338	.5409
168	.4161	.4232	.4302	.4373	.4444	.4514	.4585	.4655	.4726	.4796	.4867	.4937	.5008	.5078	.5149	.5219	.5290	.5360	.5431
174	.4182	.4253	.4323	.4394	.4465	.4535	.4606	.4676	.4747	.4817	.4888	.4958	.5029	.5099	.5170	.5240	.5311	.5381	.5452
180	.4203	.4274	.4344	.4415	.4486	.4556	.4627	.4697	.4768	.4838	.4909	.4979	.5050	.5120	.5191	.5261	.5332	.5402	.5473

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* *Compiled under the direction of D. B. Rushmore by M. W. Franklin*

TABLE II

CAPACITY

SOLID CONDUCTORS

$$C = \frac{0.003677}{\log \frac{D-r}{r}} \text{ Microfarads}$$

Microfarads per 1000 Feet of Line (2000 Feet of Wire)

Interaxial Distance, Inches	SIZE OF WIRE																		
	0000	000	00	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
3/8	......	......	......	.14710	.03160	.01812	.01303	.01030	.00861	.00743	.00688	.00589	.00526	.00493	.00458	.00427	.00401	.00377	.00357
1/2	.05270	.02315	.01531	.01156	.00941	.00800	.00699	.00622	.00563	.00515	.00476	.00444	.00408	.00389	.00367	.00348	.00331	.00315	.00302
3/4	.01038	.00864	.00746	.00659	.00591	.00539	.00495	.00458	.00427	.00401	.00378	.00357	.00335	.00323	.00309	.00295	.00283	.00272	.00262
1	.00701	.00625	.00564	.00516	.00476	.00443	.00414	.00389	.003677	.00349	.00331	.00316	.00299	.00269	.00278	.00267	.00257	.00248	.00240
2	.00415	.00390	.00368	.00349	.00332	.00317	.00302	.00290	.00278	.00267	.00258	.00248	.00238	.00232	.00225	.00218	.00212	.00205	.00200
3	.00340	.00324	.00307	.00296	.00284	.00273	.00263	.00253	.00244	.00236	.00229	.00222	.00213	.00208	.00202	.00197	.00192	.00187	.00182
4	.00303	.00290	.00279	.00268	.00258	.00249	.00240	.00232	.00225	.00218	.00212	.00206	.00199	.00194	.00190	.00185	.00180	.00176	.00171
5	.00279	.00268	.00258	.00249	.00241	.00233	.00226	.00219	.00212	.00206	.00200	.00195	.00189	.00185	.00180	.00176	.00172	.00168	.00164
6	.00263	.00253	.00244	.00236	.00229	.00222	.00215	.00208	.00203	.00197	.00192	.00187	.00181	.00178	.00173	.00169	.00166	.00162	.00158
7	.00250	.00242	.00284	.00226	.00219	.00213	.00207	.00201	.00195	.00190	.00185	.00181	.00175	.00172	.00168	.00164	.00161	.00157	.00154
8	.00240	.00232	.00225	.00218	.00212	.00206	.00200	.00195	.00190	.00185	.00180	.00176	.00171	.00168	.00164	.00160	.00157	.00153	.00150
9	.00232	.00225	.00218	.00212	.00206	.00200	.00195	.00190	.00185	.00180	.00176	.00172	.00167	.00164	.00160	.00157	.00153	.00150	.00147
10	.00226	.00219	.00212	.00206	.00201	.00195	.00190	.00185	.00181	.00176	.00172	.00168	.00163	.00160	.00157	.00154	.00150	.00147	.00144
11	.00220	.00213	.00207	.00202	.00196	.00191	.00186	.00181	.00177	.00172	.00169	.00165	.00160	.00157	.00154	.00151	.00148	.00145	.00142
12	.00215	.00209	.00203	.00197	.00192	.00187	.00182	.00178	.00174	.00170	.00166	.00162	.00158	.00155	.00152	.00149	.00146	.00143	.00140
15	.00203	.00198	.00192	.00187	.00183	.00178	.00174	.00170	.00166	.00162	.00159	.00156	.00151	.00149	.00146	.00143	.00140	.00138	.00135
18	.00195	.00190	.00185	.00180	.00176	.00172	.00168	.00164	.00160	.00157	.00153	.00150	.00147	.00144	.00142	.00139	.00136	.00134	.00131
21	.00188	.00183	.00179	.00174	.00170	.00166	.00163	.00159	.00156	.00152	.00149	.00146	.00143	.00141	.00138	.00135	.00133	.00130	.00128
24	.00182	.00178	.00174	.00170	.00166	.00162	.00159	.00155	.00152	.00149	.00146	.00143	.00140	.00138	.00135	.00132	.00130	.00128	.00126
30	.00174	.00170	.00166	.00162	.00159	.00155	.00152	.00149	.00146	.00143	.00140	.00138	.00135	.00133	.00130	.00128	.00126	.00124	.00122
36	.00168	.00164	.00160	.00157	.00153	.00150	.00147	.00144	.00142	.00139	.00136	.00134	.00131	.00129	.00127	.00125	.00122	.00120	.00118
42	.00163	.00159	.00156	.00152	.00149	.00146	.00143	.00141	.00138	.00135	.00133	.00131	.00128	.00126	.00124	.00122	.00120	.00118	.00116
48	.00159	.00155	.00152	.00149	.00146	.00143	.00140	.00138	.00135	.00133	.00130	.00128	.00125	.00123	.00122	.00120	.00118	.00116	.00114
54	.00155	.00152	.00149	.00146	.00143	.00140	.00138	.00135	.00133	.00130	.00128	.00126	.00123	.00121	.00120	.00118	.00116	.00114	.00112
60	.00152	.00149	.00146	.00143	.00140	.00138	.00135	.00133	.00130	.00128	.00126	.00124	.00121	.00120	.00118	.00116	.00114	.00112	.00111
66	.00150	.00147	.00144	.00141	.00138	.00136	.00133	.00131	.00129	.001260	.00124	.00122	.00120	.00118	.00116	.00114	.001130	.001110	.001093
72	.00147	.00144	.00142	.00139	.00136	.00134	.00131	.00129	.00127	.001246	.001226	.001205	.001182	.001167	.001150	.001130	.001114	.001097	.001080
78	.001454	.001425	.001400	.001371	.001346	.001321	.001298	.001275	.001254	.001232	.001212	.001191	.001168	.001155	.001136	.001119	.001103	.001086	.001070
84	.001436	.001407	.001382	.001355	.001330	.001307	.001283	.001261	.001240	.001218	.001198	.001178	.001157	.001142	.001125	.001108	.001092	.001075	.001060
90	.001420	.001392	.001366	.001340	.001316	.001292	.001270	.001248	.001227	.001207	.001187	.001168	.001145	.001132	.001115	.001098	.001083	.001065	.001050
96	.001403	.001377	.001352	.001326	.001303	.001280	.001257	.001237	.001216	.001196	.001177	.001158	.001136	.001122	.001105	.001088	.001073	.001057	.001042
102	.001390	.001363	.001338	.001314	.001290	.001268	.001246	.001224	.001205	.001185	.001167	.001148	.001126	.001113	.001097	.001080	.001064	.001050	.001035
108	.001376	.001351	.001327	.001302	.001280	.001257	.001235	.001216	.001195	.001176	.001158	.001139	.001117	.001105	.001089	.001073	.001057	.001042	.001028
114	.001364	.001339	.001315	.001292	.001268	.001247	.001227	.001206	.001186	.001167	.001150	.001131	.001110	.001098	.001081	.001065	.001050	.001035	.001020
120	.001352	.001328	.001305	.001282	.001260	.001238	.001217	.001197	.001178	.001160	.001141	.001123	.001102	.001090	.001074	.001058	.001044	.001028	.001015
126	.001342	.001318	.001294	.001272	.001250	.001230	.001208	.001188	.001170	.001152	.001134	.001115	.001095	.001083	.001068	.001052	.001037	.001023	.001009
132	.001332	.001308	.001285	.001262	.001241	.001220	.001200	.001180	.001162	.001145	.001126	.001110	.001090	.001077	.001062	.001046	.001031	.001016	.001003
138	.001323	.001299	.001277	.001256	.001233	.001213	.001194	.001175	.001156	.001137	.001120	.001104	.001083	.001071	.001055	.001040	.001025	.001011	.000998
144	.001315	.001291	.001268	.001246	.001226	.001206	.001186	.001167	.001148	.001130	.001113	.001097	.001077	.001065	.001050	.001035	.001020	.001006	.000993
150	.001305	.001283	.001261	.001240	.001218	.001200	.001180	.001160	.001142	.001125	.001108	.001092	.001072	.001080	.001045	.001030	.001015	.001002	.000988
156	.001298	.001276	.001253	.001232	.001212	.001193	.001173	.001155	.001135	.001119	.001103	.001086	.001066	.001055	.001040	.001025	.001011	.000997	.000983
162	.001290	.001269	.001246	.001228	.001206	.001185	.001167	.001149	.001130	.001113	.001097	.001080	.001061	.001050	.001035	.001020	.001006	.000993	.000980
168	.001283	.001262	.001241	.001220	.001200	.001180	.001161	.001142	.001125	.001108	.001092	.001075	.001056	.001045	.001030	.001017	.001002	.000998	.000976
174	.001277	.001255	.001233	.001213	.001193	.001174	.001156	.001138	.001120	.001104	.001087	.001071	.001052	.001040	.001026	.001012	.000998	.000984	.000972
180	.001270	.001248	.001228	.001207	.001187	.001169	.001150	.001132	.001115	.001100	.001083	.001067	.001048	.001036	.001022	.001007	.000994	.000980	.000968

INDUCTIVE REACTANCE

TABLE III

$X = \left(0.1571\ L\right)$ Ohms

SOLID CONDUCTORS

Ohms per 1000 Feet (for one wire)

25 CYCLES

Interaxial Distance, Inches	SIZE OF WIRE																		
	0000	000	00	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
3/8	...	...	.00926	.01037	.01148	.01259	.01370	.01481	.01591	.01702	.01813	.01924	.02035	.02146	.02257	.02368	.02479	.02590	.02701
1/2	.00982	.01093	.01204	.01315	.01426	.01537	.01648	.01759	.01870	.01981	.02092	.02203	.02314	.02425	.02536	.02647	.02758	.02869	.02980
3/4	.01368	.01479	.01590	.01701	.01812	.01923	.02034	.02145	.02256	.02367	.02478	.02589	.02700	.02811	.02922	.03033	.03144	.03255	.03366
1.	.01644	.01755	.01866	.01977	.02088	.02199	.02310	.02421	.02532	.02643	.02754	.02865	.02976	.03087	.03198	.03309	.03420	.03531	.03642
2	.02306	.02417	.02528	.02639	.02750	.02861	.02972	.03083	.03194	.03305	.03416	.03527	.03638	.03749	.03860	.03971	.04082	.04193	.04304
3	.02691	.02802	.02913	.03024	.03135	.03246	.03357	.03468	.03579	.03690	.03801	.03912	.04023	.04134	.04245	.04356	.04467	.04578	.04689
4	.02968	.03079	.03190	.03301	.03412	.03523	.03634	.03745	.03856	.03967	.04078	.04189	.04300	.04411	.04522	.04633	.04744	.04855	.04966
5	.03181	.03292	.03403	.03514	.03625	.03736	.03847	.03958	.04069	.04180	.04291	.04402	.04513	.04624	.04735	.04846	.04957	.05068	.05179
6	.03353	.03464	.03575	.03686	.03797	.03908	.04019	.04130	.04241	.04352	.04463	.04574	.04685	.04796	.04907	.05018	.05129	.05240	.05351
7	.03501	.03612	.03723	.03834	.03945	.04056	.04167	.04278	.04389	.04500	.04611	.04722	.04833	.04944	.05055	.05166	.05277	.05388	.05499
8	.03629	.03740	.03851	.03962	.04073	.04184	.04295	.04406	.04517	.04628	.04739	.04850	.04961	.05072	.05183	.05294	.05405	.05516	.05627
9	.03742	.03853	.03964	.04075	.04186	.04297	.04408	.04519	.04630	.04741	.04852	.04963	.05074	.05185	.05296	.05407	.05518	.05629	.05740
10	.03843	.03954	.04065	.04176	.04287	.04398	.04509	.04620	.04731	.04842	.04953	.05064	.05175	.05286	.05397	.05508	.05619	.05730	.05841
11	.03933	.04044	.04155	.04266	.04377	.04488	.04599	.04710	.04821	.04932	.05043	.05154	.05265	.05376	.05487	.05598	.05709	.05820	.05931
12	.04015	.04126	.04237	.04348	.04459	.04570	.04681	.04792	.04903	.05014	.05125	.05236	.05347	.05458	.05569	.05680	.05791	.05902	.06013
15	.04230	.04341	.04452	.04563	.04674	.04785	.04896	.05007	.05118	.05229	.05340	.05451	.05562	.05673	.05784	.05895	.06006	.06117	.06228
18	.04403	.04514	.04625	.04736	.04847	.04958	.05069	.05180	.05291	.05402	.05513	.05624	.05735	.05846	.05957	.06068	.06179	.06290	.06401
21	.04551	.04662	.04773	.04884	.04995	.05106	.05217	.05328	.05439	.05550	.05661	.05772	.05883	.05994	.06105	.06216	.06327	.06438	.06549
24	.04678	.04789	.04900	.05011	.05122	.05233	.05344	.05455	.05566	.05677	.05788	.05899	.06010	.06121	.06232	.06343	.06454	.06565	.06676
30	.04892	.05003	.05114	.05225	.05336	.05447	.05558	.05669	.05780	.05891	.06002	.06113	.06224	.06335	.06446	.06557	.06668	.06779	.06890
36	.05064	.05175	.05286	.05397	.05508	.05619	.05730	.05841	.05952	.06063	.06174	.06285	.06396	.06507	.06618	.06729	.06840	.06951	.07062
42	.05214	.05325	.05436	.05547	.05658	.05769	.05880	.05991	.06102	.06213	.06324	.06435	.06546	.06657	.06768	.06879	.06990	.07101	.07212
48	.05339	.05450	.05561	.05672	.05783	.05894	.06005	.06116	.06227	.06338	.06449	.06560	.06671	.06782	.06893	.07004	.07115	.07226	.07337
54	.05452	.05563	.05674	.05785	.05896	.06027	.06118	.06229	.06340	.06451	.06562	.06673	.06784	.06895	.07006	.07117	.07228	.07339	.07450
60	.05553	.05664	.05775	.05886	.05997	.06108	.06219	.06330	.06441	.06552	.06663	.06774	.06885	.06996	.07107	.07218	.07329	.07440	.07551
66	.05644	.05755	.05866	.05977	.06088	.06199	.06310	.06421	.06532	.06643	.06754	.06865	.06976	.07087	.07198	.07309	.07420	.07531	.07642
72	.05727	.05838	.05949	.06060	.06171	.06282	.06393	.06504	.06615	.06726	.06837	.06948	.07059	.07170	.07281	.07392	.07503	.07614	.07725
78	.05804	.05915	.06026	.06137	.06248	.06359	.06470	.06581	.06692	.06803	.06914	.07025	.07136	.07247	.07358	.07469	.07580	.07691	.07802
84	.05875	.05986	.06097	.06208	.06319	.06430	.06541	.06652	.06763	.06874	.06985	.07096	.07207	.07318	.07429	.07540	.07651	.07762	.07873
90	.05941	.06052	.06163	.06274	.06385	.06496	.06607	.06718	.06829	.06940	.07051	.07162	.07273	.07384	.07495	.07606	.07717	.07828	.07939
96	.06002	.06113	.06224	.06335	.06446	.06557	.06668	.06779	.06890	.07001	.07112	.07223	.07334	.07445	.07556	.07667	.07778	.07889	.08000
102	.06060	.06171	.06282	.06393	.06504	.06615	.06726	.06837	.06948	.07059	.07170	.07281	.07392	.07503	.07614	.07725	.07836	.07947	.08058
108	.06115	.06226	.06337	.06448	.06559	.06670	.06781	.06892	.07003	.07114	.07225	.07336	.07447	.07558	.07669	.07780	.07891	.08002	.08113
114	.06167	.06278	.06389	.06500	.06611	.06722	.06833	.06944	.07055	.07166	.07277	.07388	.07499	.07610	.07721	.07832	.07943	.08054	.08165
120	.06216	.06327	.06438	.06549	.06660	.06771	.06882	.06993	.07104	.07215	.07326	.07437	.07548	.07659	.07770	.07881	.07992	.08103	.08214
126	.06261	.06372	.06483	.06594	.06705	.06816	.06927	.07038	.07149	.07260	.07371	.07482	.07593	.07704	.07815	.07926	.08037	.08148	.08259
132	.06305	.06416	.06527	.06638	.06749	.06860	.06971	.07082	.07193	.07304	.07415	.07526	.07637	.07748	.07859	.07970	.08081	.08192	.08303
138	.06348	.06459	.06570	.06681	.06792	.06903	.07014	.07125	.07236	.07347	.07458	.07569	.07680	.07791	.07902	.08013	.08124	.08235	.08346
144	.06389	.06500	.06611	.06722	.06833	.06944	.07055	.07166	.07277	.07388	.07499	.07610	.07721	.07832	.07943	.08054	.08165	.08276	.08387
150	.06428	.06539	.06650	.06761	.06872	.06983	.07094	.07205	.07316	.07427	.07538	.07649	.07760	.07871	.07982	.08093	.08204	.08315	.08426
156	.06465	.06577	.06688	.06799	.06910	.07021	.07132	.07243	.07354	.07465	.07576	.07687	.07798	.07909	.08020	.08131	.08242	.08353	.08464
162	.06502	.06613	.06724	.06835	.06946	.07057	.07168	.07279	.07390	.07501	.07612	.07723	.07834	.07945	.08056	.08167	.08278	.08389	.08500
168	.06536	.06647	.06758	.06869	.06980	.07091	.07202	.07313	.07424	.07535	.07646	.07757	.07868	.07979	.08090	.08201	.08312	.08423	.08534
174	.06569	.06680	.06791	.06902	.07013	.07124	.07235	.07346	.07457	.07568	.07679	.07790	.07901	.08012	.08123	.08234	.08345	.08456	.08567
180	.06602	.06713	.06824	.06935	.07046	.07157	.07268	.07379	.07490	.07601	.07712	.07823	.07934	.08045	.08156	.08267	.08378	.08489	.08600

INDUCTIVE REACTANCE

TABLE IV

X = (0.377 L) Ohms

SOLID CONDUCTORS

Ohms Per 1000 Feet (for one wire)

60 CYCLES

Interaxial Distance Inches	SIZE OF WIRE																		
	0000	000	00	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
3/8			.02228	.02494	.07760	.03026	.03292	.03558	.03824	.04090	.04356	.04622	.04888	.05154	.05420	.05686	.05952	.06218	.06484
1/2	02356	.07622	02888	.03154	.03420	.03686	.03952	.04218	.04484	.04750	.05016	.05282	.05548	.05814	.06080	.06346	.06612	.06878	.07144
3/4	03284	.03550	.03816	.04082	.04348	.04614	.04880	.05146	.05412	.05678	.05944	.06210	.06476	.06742	.07008	.07274	.07540	.07806	.08072
1	03945	.04211	.04477	.04743	.05009	.05275	.05541	.05807	.06073	.06339	.06605	.06871	.07137	.07403	.07669	.07935	.09201	.03467	.08733
2	05534	.05800	.06066	.06332	.06598	.06864	.07130	.07396	.07662	.07928	.08194	.08460	.08726	.08992	.09258	.09524	.09790	.10056	.10322
3	.06458	.06724	.06990	.07256	.07522	.07788	.08054	.08320	.08586	.08852	.09118	.09384	.09650	.09916	.10182	.10448	.10714	.10980	.11246
4	.07123	.07389	.07655	.07921	.08187	.08453	.08719	.08985	.09251	.09517	.09783	.10049	.10315	.10581	.10847	.11113	.11379	.11645	.11911
5	.07634	.07900	08166	.08432	08698	.08964	.09230	.09496	.09762	.10028	.10294	.10560	.10826	.11092	.11358	.11624	.11890	.12156	.12422
6	.08047	.08313	.08579	.08845	.09111	.09377	.09643	.09909	.10175	.10441	.10707	.10973	.11239	.11505	.11771	.12037	.12303	.12569	.12835
7	.08403	.08669	.08935	.09201	.09467	.09733	.09999	.10265	.10531	.10797	.11063	.11329	.11595	.11861	.12127	.12393	.12659	.12925	.13191
8	08708	.08974	.09240	.09506	.09772	.10038	.10304	.10570	.10836	.11102	.11368	.11634	.11900	.12166	.12432	.12698	.12964	.13230	.13496
9	.08980	.09246	.09512	.09778	.10044	.10310	.10576	.10842	.11108	.11374	.11640	.11906	.12172	.12438	.12704	.12970	.13236	.13502	.13768
10	.09223	.09489	.09755	.10021	.10287	.10553	.10819	.11085	.11351	.11617	.11883	.12149	.12415	.12681	.12947	.13213	.13479	.13745	.14011
11	.09440	.09706	.09972	.10238	.10504	.10770	.11036	.11302	.11568	.11834	.12100	.12366	.12632	.12898	.13164	.13430	.13696	.13962	.14228
12	.09635	.09901	.10167	.10433	.10699	.10965	.11231	.11497	.11763	.12029	.12295	.12561	.12827	.13093	.13359	.13625	.13891	.14157	.14423
15	.10153	.10419	.10685	.10951	.11217	.11483	.11749	.12015	.12281	.12547	.12813	.13079	.13345	.13611	.13877	.14143	.14409	.14675	.14941
18	.10571	.10833	.11099	.11365	.11631	.11897	.12163	.12429	.12695	.12961	.13227	.13493	.13759	.14025	.14291	.14557	.14823	.15089	.15355
21	.10921	11187	.11453	.11719	.11985	.12251	.12517	.12783	.13049	.13315	.13581	.13847	.14113	.14379	.14645	.14911	.15177	.15443	.15709
24	.11227	.11493	.11759	.12025	.12291	.12557	.12823	.13089	.13355	.13621	.13887	.14153	.14419	.14685	.14951	.15217	.15483	.15749	.16015
30	.11740	.12006	.12272	.12538	.12804	.13070	.13336	.13602	.13868	.14134	.14400	.14666	.14932	.15198	.15464	.15730	.15996	.16262	.16528
36	.12154	.12420	.12686	.12952	.13218	.13484	.13750	.14016	.14282	.14548	.14814	.15080	.15346	.15612	.15878	.16144	.16410	.16676	.16942
42	.12512	.12778	.13044	.13310	.13576	.13842	.14108	.14374	.14640	.14906	.15172	.15438	.15704	.15970	.16236	.16502	.16768	.17034	.17300
48	.12814	.13080	.13346	.13612	.13878	.14144	.14410	.14676	.14942	.15208	.15474	.15740	.16006	.16272	.16538	.16804	.17070	.17336	.17602
54	.13085	.13351	.13617	.13883	.14149	.14415	.14681	.14947	.15213	.15479	.15745	.16011	.16277	.16543	.16809	.17075	.17341	.17607	.17873
60	.13327	.13593	.13859	.14125	.14391	.14657	.14923	.15189	.15455	.15721	.15987	.16253	.16519	.16785	.17051	.17317	.17583	.17849	.18115
66	.13545	.13811	.14077	.14343	.14609	.14875	.15141	.15407	.15673	.15939	.16205	.16471	.16737	.17003	.17269	.17535	.17801	.18067	.18333
72	.13745	.14011	.14277	.14543	.14809	.15075	.15341	.15607	.15873	.16139	.16405	.16671	.16937	.17203	.17469	.17735	.18001	.19267	.18533
78	.13930	.14196	.14462	.14728	.14994	.15260	.15526	.15792	.16058	.16324	.16590	.16856	.17122	.17388	.17654	.17920	.18186	.18452	.18718
84	.14099	.14365	.14631	.14897	.15163	.15429	.15695	.15961	.16227	.16493	.16759	.17025	.17291	.17557	.17823	.18089	.18355	.18621	.15887
90	.14258	.14524	.14790	.15056	.15322	.15588	.15854	.16120	.16386	.16652	.16918	.17184	.17450	.17716	.17982	.18248	.18514	.18780	.19046
96	.14405	.14671	.14937	.15203	.15469	.15735	.16001	.16267	.16533	.16799	.17065	.17331	.17597	.17863	.18129	.18395	.18661	.18927	.19193
102	.14545	.14811	.15077	.15343	.15609	.15875	.16141	.16407	.16673	.16939	.17205	.17471	.17737	.18003	.18269	.18535	.18801	.19067	.19333
108	.14676	.14942	.15208	.15474	.15740	.16006	.16272	.16538	.16804	.17070	.17336	.17602	.17868	.18134	.18400	.18666	.18932	.19198	.19464
114	.14801	.15067	.15333	.15599	.15865	.16131	.16397	.16663	.16929	.17195	.17461	.17727	.17993	.18259	.18525	.18791	.19057	.10323	.19589
120	.14918	.15184	.15450	.15716	.15982	.16248	.16514	.16780	.17046	.17312	.17578	.17844	.18110	.18376	.18642	.18908	.19174	.19440	19706
126	.15027	.15293	.15559	.15825	16091	.16357	.16623	.16889	.17155	.17421	.17687	.17953	.18219	.18485	.18751	.19017	.19283	.19549	.19815
132	.15133	.15399	.15665	.15931	.16197	.16463	.16729	.16995	.17261	.17527	.17793	.18059	.18325	.18591	.18857	.19123	.19389	.19655	.19921
138	15234	.15500	.15766	.16032	16298	.16564	.16830	.17096	.17362	.17628	.17894	.18160	.18426	.18692	.18958	.19224	.19490	.19756	20022
144	.15332	.15598	.15864	.16130	.16396	.16662	.16928	.17194	.17460	.17726	.17992	.18258	.18524	.18790	.19056	.19322	.19588	.19854	.20120
150	15427	.15693	.15959	.16225	.16491	.16757	.17023	.17289	.17555	.17821	.18087	.18353	.18619	.18885	.19151	.19417	.19683	.19949	20215
156	15517	.15783	.16049	.16315	.16581	.16847	.17113	.17379	.17645	.17911	.18177	.18443	.18709	.18975	.19241	.19507	.19773	.20039	20305
162	.15604	.15870	.16136	.16402	.16668	.16934	.17200	.17466	.17732	.17998	.18264	.18530	.18796	.19062	.19328	.19594	.19860	.20126	.20392
168	.15686	.15952	.16218	.16484	.16750	.17016	.17282	.17548	.17814	.18080	.18346	.18612	.18878	.19144	.19410	.19676	.19942	.20208	.20474
174	.15766	.16032	.16298	.16564	.16830	.17096	.17362	.17628	.17894	.18160	.18426	.18692	.18958	.19224	.19490	.19756	.20022	.20288	.20554
180	.15845	.16111	.16377	.16643	.16909	.17175	.17441	.17707	.17973	.18239	.18505	.18771	.19037	.19303	.19569	.19835	.20101	.20367	.20633

TABLE V

INDUCTIVE REACTANCE

$X = (0.6283\ L)$ Ohms

Ohms per 1000 Feet (for one wire)

SOLID CONDUCTORS
100 CYCLES*

Interaxial Distance, Inches	SIZE OF WIRE																		
	0000	000	00	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
3/8	. . . .	. . . .	.03713	.04156	.04599	.05042	.05485	.05928	.06371	.06814	.07257	.07700	.08143	.08586	.09029	.09472	.09915	.10358	.10801
1/2	.03927	.04370	.04813	.05256	.05699	.06142	.06585	.07028	.07471	.07914	.08357	.08800	.09243	.09686	.10129	.10572	.11015	.11458	.11901
3/4	.05473	.05916	.06359	.06802	.07245	.07688	.08131	.08574	.09017	.09460	.09903	.10346	.10789	.11232	.11675	.12118	.12561	.13004	.13447
1	.06575	.07018	.07461	.07904	.08347	.08790	.09233	.09676	.10119	.10562	.11005	.11448	.11891	.12334	.12777	.13220	.13663	.14106	.14549
2	.09223	.09666	.10109	.10552	.10995	.11438	.11881	.12324	.12767	.13210	.13653	.14096	.14539	.14982	.15425	.15868	.16311	.16754	.17197
3	.10763	.11206	.11649	.12092	.12535	.12978	.13421	.13864	.14307	.14750	.15193	.15636	.16079	.16522	.16965	.17408	.17851	.18294	.18737
4	.11871	.12314	.12757	.13200	.13643	.14086	.14529	.14972	.15415	.15858	.16301	.16744	.17187	.17630	.18073	.18516	.18959	.19402	.19845
5	.12723	.13166	.13609	.14052	.14495	.14938	.15381	.15824	.16267	.16710	.17153	.17596	.18039	.18482	.18925	.19368	.19811	.20254	.20697
6	.13411	.13854	.14297	.14740	.15183	.15626	.16069	.16512	.16955	.17398	.17841	.18284	.18727	.19170	.19613	.20056	.20499	.20942	.21385
7	.14005	.14448	.14891	.15334	.15777	.16220	.16663	.17106	.17549	.17992	.18435	.18878	.19321	.19764	.20207	.20650	.21093	.21536	.21979
8	.14514	.14957	.15400	.15843	.16286	.16729	.17172	.17615	.18058	.18501	.18944	.19387	.19830	.20273	.20716	.21159	.21602	.22045	.22488
9	.14967	.15410	.15853	.16296	.16739	.17182	.17625	.18068	.18511	.18954	.19397	.19840	.20283	.20726	.21169	.21612	.22055	.22498	.22941
10	.15371	.15814	.16257	.16700	.17143	.17586	.18029	.18472	.18915	.19358	.19801	.20244	.20687	.21130	.21573	.22016	.22459	.22902	.23345
11	.15733	.16176	.16619	.17062	.17505	.17948	.18391	.18834	.19277	.19720	.20163	.20606	.21049	.21492	.21935	.22378	.22821	.23264	.23707
12	.16059	.16502	.16945	.17388	.17831	.18274	.18717	.19160	.19603	.20046	.20489	.20932	.21375	.21818	.22261	.22704	.23147	.23590	.24033
15	.16921	.17364	.17807	.18250	.18693	.19136	.19579	.20022	.20465	.20908	.21351	.21794	.22237	.22680	.23123	.23566	.24009	.24452	.24895
18	.17612	.18055	.18498	.18941	.19384	.19827	.20270	.20713	.21156	.21599	.22042	.22485	.22928	.23371	.23814	.24257	.24700	.25143	.25586
21	.18202	.18645	.19088	.19531	.19974	.20417	.20860	.21303	.21746	.22189	.22632	.23075	.23518	.23961	.24404	.24847	.25290	.25733	.26176
24	.18711	.19154	.19597	.20040	.20483	.20926	.21369	.21812	.22255	.22698	.23141	.23584	.24027	.24470	.24913	.25356	.25799	.26242	.26685
30	.19566	.20009	.20452	.20895	.21338	.21781	.22224	.22667	.23110	.23553	.23996	.24439	.24882	.25325	.25768	.26211	.26654	.27097	.27540
36	.20257	.20700	.21143	.21586	.22029	.22472	.22915	.23358	.23801	.24244	.24687	.25130	.25573	.26016	.26459	.26902	.27345	.27788	.28231
42	.20854	.21297	.21740	.22183	.22626	.23069	.23512	.23955	.24398	.24841	.25284	.25727	.26170	.26613	.27056	.27499	.27942	.28385	.28828
48	.21357	.21800	.22243	.22686	.23129	.23572	.24015	.24458	.24901	.25344	.25787	.26230	.26673	.27116	.27559	.28002	.28445	.28888	.29331
54	.21809	.22252	.22695	.23138	.23581	.24024	.24467	.24910	.25353	.25796	.26239	.26682	.27125	.27568	.28011	.28454	.28897	.29340	.29783
60	.22211	.22654	.23097	.23540	.23983	.24426	.24869	.25312	.25755	.26198	.26641	.27084	.27527	.27970	.28413	.28856	.29299	.29742	.30185
66	.22575	.23018	.23461	.23904	.24347	.24790	.25233	.25676	.26119	.26562	.27005	.27448	.27891	.28334	.28777	.29220	.29663	.30106	.30549
72	.22908	.23351	.23794	.24237	.24680	.25123	.25566	.26009	.26452	.26895	.27338	.27781	.28224	.28667	.29110	.29553	.29996	30439	.30882
78	.23216	.23659	.24102	.24545	.24988	.25431	.25874	.26317	.26760	.27203	.27646	.28089	.28532	.28975	.29418	.29861	.30304	.30747	.31190
84	.23499	.23942	.24385	.24828	.25271	.25714	.26157	.26600	.27043	.27486	.27929	.28372	.28815	.29258	.29701	.30144	.30587	.31030	.31473
90	.23763	.24206	.24649	.25092	.25535	.25978	.26421	.26864	.27307	.27750	.28193	.28636	.29079	.29522	.29965	.30408	.30851	.31294	.31737
96	.24008	.24451	.24894	.25337	.25780	.26223	.26666	.27109	.27552	.27995	.28438	.28881	.29324	.29767	.30210	.30653	.31096	.31539	.31982
102	.24241	.24684	.25127	.25570	.26013	.26456	.26899	.27342	.27785	.28228	.28671	.29114	.29557	.30000	.30443	.30686	.31329	.31772	.32215
108	.24460	.24903	.25346	.25789	.26232	.26675	.27118	.27561	.28004	.28447	.28890	.29333	.29776	.30219	.30662	.31105	.31548	.31991	.32434
114	.24668	.25111	.25554	.25997	.26440	.26883	.27326	.27769	.28212	.28655	.29098	.29541	.29984	.30427	.30870	.31313	.31756	.32199	.32642
120	.24863	.25306	.25749	.26192	.26635	.27078	.27521	.27964	.28407	.28850	.29293	.29736	.30179	.30622	.31065	.31508	.31951	.32394	.32837
126	.25045	.25488	.25931	.26374	.26817	.27260	.27703	.28146	.28589	.29032	.29475	.29918	.30361	.30804	.31247	.31690	.32133	.32576	.33019
132	.25221	.25664	.26107	.26550	.26993	.27436	.27879	.28332	.28765	.29208	.29651	.30094	.30537	.30980	.31423	.31866	.32309	.32752	.33195
138	.25390	.25833	.26276	.26719	.27162	.27605	.28048	.28491	.28934	.29377	.29820	.30263	.30706	.31149	.31592	.32035	.32478	.32931	.33364
144	.25554	.25997	.26440	.26883	.27326	.27769	.28212	.28655	.29098	.29541	.29984	.30427	.30870	.31313	.31756	.32199	.32642	.33085	.33528
150	.25711	.26154	.26597	.27040	.27483	.27926	.28369	.28812	.29255	.29698	.30141	.30584	.31027	.31470	.31913	.32356	.32799	.33242	.33685
156	.25862	.26305	.26748	.27191	.27634	.28077	.28520	.28963	.29406	.29849	.30292	.30735	.31178	.31621	.32064	.32507	.32950	.33393	.33836
162	.26006	.26449	.26892	.27335	.27778	.28221	.28664	.29107	.29550	.29993	.30436	.30879	.31322	.31765	.32208	.32651	.33094	.33537	.33980
168	.26144	.26587	.27030	.27473	.27916	.28359	.28802	.29245	.29688	.30131	.30574	.31017	.31460	.31903	.32346	.32789	.33232	.33675	.34118
174	.26276	.26719	.27162	.27605	.28048	.28491	.28934	.29377	.29820	.30263	.30706	.31149	.31592	.32035	.32478	.32921	.33364	.33807	.34250
180	.26408	.26851	.27294	.27736	.28179	.28622	.29065	.29508	.29951	.30394	.30837	.31280	.31723	.32166	.32609	.33052	.33495	.33938	.34381

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* This table is furnished for calculating inductive reactance at any frequency, values at any frequency being proportional to those here given.

GEARS AND PINIONS

By J. M. Darke

The materials used in the manufacture of gears and pinions are cast iron, malleable cast iron, cast steel, forged steel, copper alloys, rawhide and paper. The selection of a particular material is governed by the service it must perform and by its cost.

Cast iron is largely used for the gears and pinions of machine tools, textile machinery, shoe machinery and other forms of machinery where the service is light, or where large masses of the metal can be used. The iron is melted in a cupola and cast in sand molds of the desired shape. As it cannot be forged or rolled, it is always used in the form of a casting. Cast iron when melted is very fluid and therefore conforms readily to the shape of the mold, thus producing castings that are clean, sharp, and true to the pattern. On account of this property, gears are frequently made of cast iron with the teeth cast in place, but for more accurate gearing the blanks are cast and the teeth are afterwards machined. Cast iron can be machined easily and rapidly, and, as the first cost is low, it is used wherever service conditions will permit. Cast iron suitable for gears should have about the following physical properties:—

Tensile strength .	25,000 to 30,000 lbs. per sq. in.
Transverse strength	1 in. square bar, 12 in. between supports, loaded in the middle with 3000 lbs.
Deflection .	0.20 in.
Hardness .	196

Malleable cast iron is used to a small extent for gears, where conditions of service require a little more strength and ductility than is afforded by cast iron. Malleable iron is easily cast and machined, but due to the method of manufacture its cost is greater than that of cast iron and in some cases is equal to or greater than that of steel castings. It is seldom made in sections thicker than 1 to 1½ in., for the reason that thicker sections cannot be converted in the annealing. It is used principally for shapes that are so intricate or thin that steel will not "run," or fill the molds, otherwise it could not compete with steel castings; in fact, many shapes formerly made in malleable iron are now made in Tropenas steel.

Good malleable iron has about the following physical properties:

Tensile strength .	40,000 to 60,000 lbs. per sq. in.
Elastic limit .	Close to tensile strength.
Elongation . .	2½ to 5 per cent.
Reduction in area	Very slight
Hardness . .	116

Steel castings are extensively used for gears and the metal is usually made in an open hearth furnace, Tropenas converter, or crucible. The open hearth furnace may be acid or basic, but as it is generally believed that "acid steel" makes better steel castings, this process is the more used.

The Tropenas converter process of making steel for castings consists in melting the mixture of pig iron and steel scrap in a cupola in the same manner as that followed for cast iron. The liquid metal is poured into a small converter, similar in many respects to a regular Bessemer converter, but differing from it in being smaller (usually 2 tons capacity), and in having the tuyeres placed in the side of the vessel instead of in the bottom. The converter is then placed at such an angle that the top of the liquid metal will come about on a level with the tuyeres. The air is consequently blown on top of the metal instead of through it, as in the regular Bessemer process. This results in a less violent agitation of the metal, and for this reason it is thought to contain less oxygen, nitrogen and other gases. The metal is blown until the character of the flame indicates that the desired carbon content has been reached, when the blast is stopped and the final additions of ferro-manganese and ferro-silicon are made.

The metal produced by this process is exceedingly hot, due to the rapid oxidation of the manganese, silicon and carbon, and it is therefore possible to make castings from Tropenas steel that are too thin and rangy to be made from open hearth steel. Very excellent steel castings can be made by the Tropenas process, but it requires more skill than the open hearth or crucible processes.

The crucible process, while used to some extent for making alloy steel castings for the automobile industry, is practically never used for making electric railway motor gear castings, since the process is very expensive as compared with others.

If gear castings are to be made by the acid open hearth, Tropenas, or crucible processes, the stock must be carefully selected to contain not more than 0.06 per cent. phosphorus or sulphur. Phosphorus in excess causes the castings to be brittle, while an excess of sulphur causes them to crack while hot, or to become "hot short." Phosphorus also seems to increase the tendency of castings to "check" or crack wherever there is an abrupt change in cross section. This latter trouble is also caused by the shrinkage of the metal against unyielding sections of the sand mold.

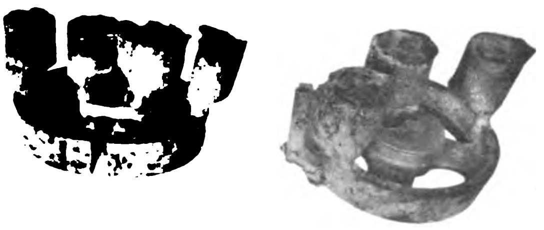

Fig. 1. Steel Casting of Gear, Showing Gate and Risers

The molds for railway motor gear castings are made of a special silica sand, the work is largely done by machines, and very perfect molds are thus secured. The sand used is damp, or "green" as it is called, to make it plastic; but before the steel is poured into the molds they must be thoroughly dried, in order to prevent surface blow holes. The drying of the molds is accomplished in large ovens heated with coke, coal or fuel oil.

Steel castings are also made in "green" sand molds, but it is not generally considered safe to make gear castings in this manner. A steel gear casting is a fairly difficult casting to make, for when the teeth are cut they must be perfectly free from all imperfections, such as blow holes, sand holes, and shrink holes. On account of the difficulty of making perfect steel castings possessing thin sections or intricate shapes, steel gears are not cast with the teeth in place, as is sometimes done with cast iron.

After the molds are poured and the castings have become fairly cool, they are cleaned and the adhering sand and metal incidental to the process of pouring, such as "gates" and "risers," is removed. The gate on a steel casting is the place where the metal enters in pouring, while the riser is a metal reservoir attached to the casting to feed the casting during cooling and thus prevent shrink holes. The castings are next carefully inspected for imperfections, and those that pass are sent to the gear cutting department.

As the strength of a steel casting is governed to a considerable extent by the amount of carbon present therein, railway motor gear castings are made of steel containing the proper proportion of carbon to suit the requirements of the service. Gear castings for motors under 75 h.p. are usually made from steel containing 0.25 to 0.30 per cent. carbon, 0.60 to 0.70 per cent manganese, 0.25 to 0.30 per cent silicon, and phosphorus and sulphur below 0.06 per cent. This steel is usually used unannealed, and has about the following physical properties:

Tensile strength .	60,000 lbs. per sq. in.
Elastic limit .	25,000 lbs. per sq. in.
Elongation . .	18 per cent. in 2 in.
Reduction of area	20 per cent.
Hardness . .	121

Gear castings for motors of 75 h.p. and larger are usually made from steel containing 0.35 to 0.40 per cent. carbon, the balance of the composition remaining the same as above. Moreover, this steel is always annealed and has about the following physical properties:

Tensile strength .	68,000 lbs. per sq. in.
Elastic limit .	30,000 lbs. per sq. in.
Elongation . .	20 per cent. in 2 in.
Reduction of area	30 per cent.
Hardness . .	154

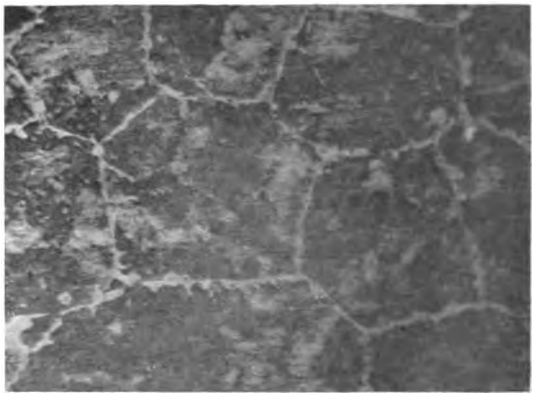

Fig. 2. 0.40% Carbon Steel, Unnealed

The strength and brittleness of a steel casting increases with the carbon content. The object of annealing is to remove the brittleness by increasing the ductility without greatly reducing the strength. This is accomplished through a change in the molecular structure of the steel. In order to obtain the best physical properties, the steel should be annealed at a certain definite temperature, the value of which varies with the amount of carbon in the steel. The temperature of the annealing furnace is determined by pyrometers, and close attention to and frequent readings of the pyrometers are required to uniformly maintain the proper temperature in all parts of the furnace. The character of the annealing can be determined either by a study of the fractured surface of steel bars, or by the microstructure. For the former method it is only necessary to break a bar and note the size of the grain, while for the latter the steel surface must be prepared by polishing and etching, and observation made through a compound microscope.

Figs. 2 and 3 show the microstructure of 0.40 per cent. carbon steel, unannealed and annealed respectively.

Physical properties of steel corresponding to Figs. 2 and 3:

	Elastic Limit	Tensile Strength	Elongation	Reduction in Area
Fig. 1	47625	96375	7%	7.75%
Fig. 2	47450	91625	16.5%	20.59%

Physical properties of steel corresponding to Fig. 3 show reduced strength due to annealing.

Pinions are usually made from forged steel, as steel of this kind is stronger and more ductile than that of a casting.

Pinion steel is usually made in an open hearth furnace, either acid or basic, though Bessemer steel may be sometimes used. If made in the acid open hearth furnace, the stock must be carefully selected to contain not more than 0.05 per cent. phosphorus and sulphur; while if made in the basic open hearth furnace, stock high in phosphorus may be used, as by this process the phosphorus can be almost entirely removed. The open hearth furnaces used for producing steel for rolling and forging differ from those used for making steel for castings only in being larger. A steel casting furnace is seldom larger than 25 tons capacity, while an ingot furnace is usually of 50 tons capacity.

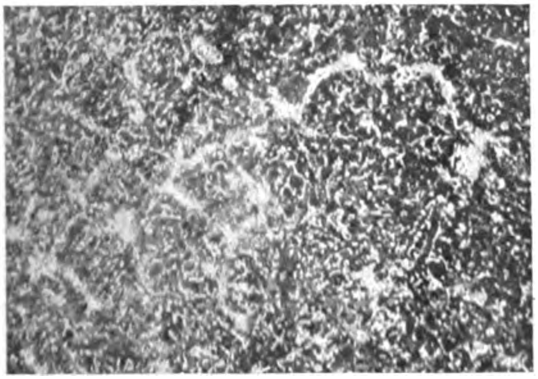

Fig. 3. 0.40% Carbon Steel, Annealed

The stock, which consists of pig iron and scrap in proportions to suit the requirements of the practice (usually 50 per cent. of each), is charged into the furnace by a charging machine. These machines are electrically operated and consist essentially of a ram which engages with the end of a charging box containing the mixture of pig iron and scrap. This box is picked up, shoved into the furnace through the door, turned upside down to allow the metal to fall into the furnace, and then removed. This operation is repeated until the required amount of metal is in the furnace. In some of the larger mills the pig iron is added in the liquid condition, after the cold scrap metal has been first placed in the bottom of the furnace.

The metal, when ready for pouring, is cast into iron molds of various sizes, depending on the practice of the mill; a common size being 20 in. square, slightly tapering at the top, and 6 to 7 feet long. As soon as the steel becomes solid on the outside, the molds are removed from the ingots by a stripping machine, this process being called "stripping." The ingot is then transferred while red hot to a large covered pit, called a "soaking pit," to await its turn at the rolls. This pit is heated, when necessary, with gas or oil fuel. The ingots are transferred from this pit to the rolling mill, where the first operation is to reduce the ingot to a billet, or bloom as it is sometimes called, by passing it through rolls until it is reduced to the size desired, usually from 6 in. to 8 in. square; the size and shape being dependent upon the purpose for which the billet is to be used. This first process is called "cogging," or blooming, and is frequently conducted in a "two-high" reversing mill. In this mill there are two rolls, and when the ingot has passed through one way, the mill is reversed and the ingot passed through the other way.

When a "three-high" mill is used the ingot is passed forward between the 1st and 2nd rolls and back through the 2nd and 3rd rolls.

In the manufacture of pinions, the process at the rolling mill ends with the production of the billet. The manufacture is resumed in the forge shop, which may be connected with the rolling mill, but which is frequently part of a distinct and separate company.

Ingots are subject to various defects which seriously affect the quality of the steel. These are "pipes," or shrinkage cavities; blow holes, or gas bubbles; segregation, or concentration of impurities; checking, or cracking due to strain while the metal is in a tender condition; and crystalization, or, as some writers call it, "ingotism." The pipe usually occurs at the top of the ingot, extending downward towards the center for some distance, and is caused by the cooling of the metal; the metal, solidifying first on the outside, shrinks away from the center, thus leaving a cavity or "pipe." The upper part of the ingot, varying from 25 to 30 per cent., is discarded during some part of the rolling process. This discarding is called "cropping," and the crop is returned to the furnace for remelting. Blow holes are caused by gases in the metal, which are given off during solidification. These gases may be in solution in the liquid metal or may be formed by a chemical reaction between iron oxide in the metal and carbon. Unless these blow holes are deep seated they are liable to cause seams in the billets, due to the fact that they split open, become oxidized, and therefore do not weld.

The elements most likely to segregate are carbon, phosphorus and sulphur. The segregation of carbon is very important in pinion work. The upper central part of an ingot may be very rich in carbon, while the lower central part may be very poor in this element. To avoid the effects of this segregation as much as possible, the lower part of the ingot to the extent of 5 per cent. is also often cropped. We have noted in our own practice a difference of 15 per cent. in carbon, from the outer edge of a 7 in. pinion to the center. This difference is especially liable to occur in high carbon steel. Segregation can be prevented to some extent by making narrow ingots. Checking or cracking may occur when the steel passes from a liquid to a solid state, for at this time it is in a pasty condition. "Ingotism" is the formation of very large crystals due to slow cooling.

Of course, any steel billet of good quality can be forged, but there is a special class of billets made for the forging trade called "forging billets." These are made from an ingot which has been cropped 5 per cent. from the bottom end and 20 per cent. from the top. They are guaranteed to be free from pipes and seam, and they are always chipped after rolling to remove surface defects which might cause seams in the subsequent forging. Ordinary re-rolling billets are made from an ingot which is cropped just enough to get the top or bottom off, no attempt being made to have the billet free from pipes; nor is the surface chipped.

Pinions should be made from forging billets, and there are two or three methods of forging in use. Probably the most common of these is to reheat a billet of the proper size and then forge it into a round bar having the rough diameter of the pinion desired. Afterwards the bar is sawed off cold to a dimension equivalent to the face of the pinion. Another method is to reheat the billet, saw off while hot a length larger than the desired pinion, forge into a round shape, and upset to get the desired length. By this process each pinion is forged individually and if properly conducted will give a pinion with less difference in strength between its longitudinal and transverse directions than a pinion cut from a forged bar. Another modification of the forging process is to use a hydraulic press for altering the shape of the metal, instead of a steam hammer. This is a very satisfactory method, as it moves the metal to the very center, and the forging operation is very thorough.

The pinion blank forgings are usually given some sort of an annealing and are then ready to be machined. The annealing may consist of a thorough heating in a furnace at a proper temperature, followed by slow cooling until a black heat is reached; or it may be the so called "sand anneal," which consists in burying the pinion blank in dry sand or ashes at that temperature which it has when forging is completed, thus somewhat retarding the cooling.

Practically all railway motor pinions are made today from straight carbon steel; that is, no alloys are used. The amount of carbon and other natural elements chosen depends on the service the pinion has to perform, the price the consumer is willing to pay, and upon the individual opinion of the engineer in charge of manufacture.

The better grades of pinions are made from acid open hearth steel forgings with carbon content ranging from 0.35 to 0.65 per cent., according to the properties desired. These may be either heat treated or untreated. The greatest demand at present is for a heat treated pinion of the very best quality.

The heat treating is usually done after the pinion is machined, and consists essentially in heating the pinion and then quenching in some liquid medium, after which it is reheated to draw the temper or to modify the hardness. The heating temperature and quenching mediums are frequently considered as trade secrets, but it is quite a well known fact that to obtain the maximum hardening, the steel must be heated just above the critical point, or that point at which the steel becomes non-magnetic, and also that the quenching must not be too severe, as otherwise rupture of the piece might occur. Oil is undoubtedly the best quenching medium.

The furnaces used in heating are of various types, but all should be so constructed and operated as to heat the pieces uniformly and without scaling. For determining the temperature of the furnaces, suitable pyrometers should be used and the composition of the treated steel kept within as narrow limits as possible, and frequently checked by chemical analysis. The treated pinion should be tested in some manner to determine the effectiveness of the heat treatment.

Another form of heat treating which is sometimes applied to pinions and gears is called case hardening. Steel for this purpose should be low in carbon and the finished article packed in some carbonaceous material, such as granulated bone or charred leather, and subjected to long continued heating above a red heat. Carbon is thus absorbed by the surface of the steel, to a depth depending on the length of time the heating is continued; but probably in no case is this depth over $\frac{1}{16}$ in. The pinion after carbonizing should be reheated and quenched in the usual manner. Gears and pinions which have been case hardened are not apt to wear well, as the pressure on the teeth is so great as to cause the soft metal under the hardened surface to flow or deform, from which the hardened surface then chips or scales off.

For severe service conditions where an ordinary cast steel gear is not strong enough, forged gear rims are used. These rims are manufactured in a manner similar to that followed in making weldless steel locomotive tires. A flat piece of steel of proper size and thickness is chosen, and a hole punched in the center. This hole is enlarged by hammering onto the horn of an anvil, after which the piece is placed in a specially designed machine which rolls it into a perfect circle of the desired dimensions. After these rims are machined, including the cutting of the teeth, they are heat treated and shrunk on to cast steel hubs.

CONSTANT POTENTIAL TRANSFORMERS

By M. O. Troy

The development of large powers, the generation of electrical energy at remote distances from the points of distribution, and the necessity of transmitting the energy at high voltages so as to hold the cost of the transmission system within limits which are not prohibitive, have forced the development of the transformer to such an extent that it represents to-day one of the foremost developments of the electrical engineer. As it stands, it requires no defense. It can be built in the largest sizes that can be transported and installed. Commercial sizes actually range from the small 10 watt potential transformer to the immense 10,000 kw. power transformer. The engineer is even prepared to design and manufacture larger capacities should they be demanded.

In its range of voltage or pressure limitations the design has passed far beyond the insulation limitations of the transmission system, 110,000 to 120,000 volts being the maximum voltage so far contemplated for high potential transmission systems, while transformers have repeatedly been built for voltages of double or triple these values. While the transformers so built have been applied to various kinds of testing and experimental investigation, they have, nevertheless, demonstrated their adaptability to transmission purposes for the time when the transmission engineer shall have overtaken the transformer engineer.

The history of transformer developments and the difficulties encountered and surmounted by the engineer would of themselves form interesting subjects for a paper, but they will have to be omitted here, as this article is intended more particularly to describe the present-day designs.

One of the earliest problems which confronted the engineer was the dissipation of heat generated within the transformer coils by their copper loss, and within the transformer core by its core loss. There was quite an interval during which the engineers were puzzled as to how to build transformers of greater than 25 kw. capacity, for fear that transformers would burn up from their own heat, and the only solution which seemed possible was to combine them in sets of two, three, or four units, so as to give

50, 75, or 100 kw. capacity. The question of dissipating the self-generated heat of the transformer is still one of the problems which requires the greatest vigilance on the part of the engineer. It is well known that as the capacity of the transformer is increased its losses are increased, though in a slightly decreasing ratio, and that the amounts of heat to be dissipated go up proportionately with the losses. The radiation is, roughly, proportionate to the exposed core and coil surfaces, neglecting, for a moment, tank surfaces and relative quantities of oil.

The external core and coil surfaces vary as the square of the linear dimensions of the transformer, while the weights, and roughly the capacities, vary as the cube of the linear dimensions; evidently, therefore, a limit exists beyond which external surfaces will not carry away the heat of the transformer. As an illustration, a 1 in. cube of unit weight has 6 square inches of surface, while a 2 in. cube of eight times the weight has only 24 square inches of surface. In other words, the weight, representing approximately both capacity and losses in the transformer, is increased eight fold, whereas the surfaces to radiate these losses are only increased four fold. This means that large transformers would burn up unless some method other than radiation from external surfaces were provided for the dissipation of the heat. The engineer's ingenuity has been strikingly displayed here in the mechanical arrangement of cores and coils so that they will be subdivided into sections, exposing surfaces many times greater than their mere external surfaces, and in providing ingenious schemes, not only for taking away the heat from the transformers, but from the compartment, vault or building in which they are installed. The methods adopted for the dissipation of heat have led to a natural sub-division of transformers into various types. They may be classed as follows:—

(1) Air cooled, natural circulation.
(2) Air cooled, forced circulation.
(3) Oil cooled, natural circulation.
(4) Oil cooled forced circulation.
(5) Oil and water cooled.

The natural air cooled constructions were quite popular in this country before the introduction of oil cooled types and before the value of oil cooling had been fully realized. The air cooled transformer is still found in extensive use abroad. It has generally been abandoned here, and about the only examples we now find of it are small transformers or compensators of moderate capacities and voltages, such as certain forms of potential transformers, arc lamp compensators, etc., or in certain instances where the underwriters will not permit the installation of oil cooled transformers. The construction of this type of transformer is extremely simple. It consists of core and coils arranged so that the external air can flow through them and carry away the self-generated heat.

The air cooled, forced circulation type is well represented by the so-called air blast transformer. This transformer has its own special field of application, and therein it has proven itself very popular. The design in most common use is built up with large, flat pancake coils, spaced apart on their core and affording liberal ducts for the circulation of air between adjacent surfaces. The core also is usually sub-divided into sections separated by air ducts. The air is supplied under pressure from a blower and flows through the coils and core in separate channels of circulation provided for it. This transformer finds its particular application in stations or substations where transformers of reasonably large capacities are required, that is, capacities beyond the usual range of the oil cooled type, and where water for the water cooled type cannot be conveniently or cheaply obtained. Its application, however, is limited to those installations which do not demand voltages in excess of 30,000 or 35,000 volts.

The oil cooled, natural circulation type covers a wide range of transformers, from the small 500 or 600 watt lighting transformer up to capacities of 400 to 500 kw., and there is an almost endless number of constructions found in this type of design. In general, however, the coils, or the coils and cores, give up their heat to a circulating oil by which it is carried to the tank surfaces and thereby dissipated into the surrounding atmosphere. The most popular type of this design is the so-called lighting transformer of 0.5 to 50 kw. which will subsequently be taken up in greater detail. The cost of units of over 400 or 500 kw. capacity becomes almost prohibitive, and for larger capacities it is found necessary to resort to some type having a forced method of circulation, not only to remove the heat from the transformer itself, but from the retaining vault, compartment or room. The voltage limits of the oil cooled transformer are very high, probably in excess of 500,000 volts.

Oil cooled, forced circulation designs find their field in extremely large units, that is, in excess of 3,000 or possibly 5,000 kw. The principles upon which this transformer dissipates its heat are very similar to those of the small oil cooled design, except that the oil is carried away from the transformer by means of circulating pumps and passed through some cooling medium such as air or water, after which it is brought back to the transformer and again circulated through it.

The oil and water cooled type is the most popular of all designs for large and high voltage power systems. In general construction it is very similar to the air blast transformer, except that the transformer is submerged in and insulated by oil and is provided with cooling coils placed in the oil, through which water flows and carries away the heat.

There are many phases of the transformer problem, any one of which would afford a most interesting subject for a paper, and it is realized that in this day of specializing, some one phase of the subject should be selected and specifically discussed to make the paper of interest to the engineer.

The transformer which is most generally manufactured and is probably of the greatest interest to the largest number of engineers, is the oil cooled transformer of the so-called lighting type, of capacities of 0.5 to 50 kw., with primary voltages of approximately 2200 and secondary voltages of 110/220 or 122/244. It is this type of transformer which demands the interest of practically every central station manager in the country, and, with the above general remarks, it is proposed to discuss this class of transformer in detail during the remainder of this paper.

The time is not far distant when the demand for this transformer will probably reach the enormous magnitude of 100,000 units per year. It is now being produced by many manufacturers, the largest of which have specialized on it to an unusual degree, devoting great attention to its perfection and manufacture.

There was a time when all transformers of this type were inefficient and poorly insulated, and the best of them were bad. To-day it is doubtful if a really bad transformer is turned out by any manufacturer, and the best of them require very careful analysis and study to determine their relative advantages, particularly when they have to meet the diversified requirements of the central station. By this I mean stations in which the cost of power is high, and those in which the cost is low; stations that are loaded down at their peak load demands, and those that have a surplus capacity at all hours of the day; stations which have a large peak and a small average load, and those that have a good load factor throughout the greater portion of the 24 hours.

The present-day manufacturer, in the exploitation of his particular type of transformer, is very prone to pick out some feature or quality in his product which he believes has an advantage over that of other manufacturers, and to exploit this particular feature to the exclusion of other characteristics or qualities of his transformer. Many fallacies have arisen because of this fact, and it is the particular purpose of this paper to try to show what characteristics are necessary and what should be avoided in purchasing transformers, and to try and dispel certain illusions which have arisen as a result of popular advertising.

The first point which interests the central station manager is safety. It is difficult to state the sequence of the other points in matter of importance, but they are as follows: durability, annual cost of operation (which involves both core and copper losses), regulation, capacity for overload, exciting currents, and permanency of losses.

Safety comes first, because the transformer is supposed to take the high voltage, which is dangerous, and convert it into a voltage for house distribution which may be considered safe. If the transformer does not do this, and the high primary voltage is allowed to pass from the primary to the secondary and thus into the house, it endangers human life and creates a possibility of loss of property from fire. Safety results from the quality of the insulation, its permanency, ability to exclude moisture, and the freedom of the transformer from local or general abnormal heating. Outside the question of the co-relation between safety and durability, the latter quality has its greatest effect upon the depreciation account and continuity of service. Obviously a transformer which only has an average life of five years must be charged up on the depreciation account at a higher rate than one which lasts ten or twenty years.

The annual cost of operation, at least certain phases of it, is probably given more detailed study by the would-be purchaser than any other phase of the transformer problem. It is an enormously important subject, but is one which is sometimes given undue consideration, or possibly certain phases of it are assigned unreasonable values. No definite rules for judging a transformer by its annual cost of operation can be laid down. General suggestions, however, can be applied by the central station manager to the conditions which exist in his particular station so that he can judge the matter for himself.

Of first importance is the core loss of the transformer, which continues for 24 hours of the day and 365 days of the year. The second is copper loss, which varies as the square of the load, is zero at no load, and has its maximum value at full load. The equivalent full load copper loss under varying conditions averages from 3 hours to 24 hours per day. Probably for an average central station the equivalent of four hours at full load copper loss per day is about correct.

The third item of importance is the interest and depreciation account. This has to be considered under the head of interest and depreciation on the transformer, and, in some cases, interest and depreciation on a portion of the central station building and its equipment. In other cases, to be exact, it may be necessary to consider the cost of such a portion of the transmission losses as are caused by the transformer losses, and also to charge up a portion of the interest and depreciation on transmission lines to the transformer, where any additional expense in installing the transmission system is incurred solely on account of transformer losses. The question of transmission losses due to transformer losses, and interest and depreciation on the transmission system because of these losses, can nearly always be neglected.

As a specific example under annual cost of operation, suppose we take the following transformers:

Core loss, 80 watts, (0.080 kw.).
Copper loss, 150 watts, (0.150 kw.).
Price, $81.00.
Interest and depreciation, 10 per cent.
Cost of station and equipment, $150.00 per kw.

The annual cost of operation at two cents per kilowatt hour, on the basis of 24 hours per day for core loss and equivalent full load copper loss of four hours per day, would be as follows:

Core loss = 0.080 × 24 × 365 × 0.02 . . = $14.02
Copper loss = 0.150 × 4 × 365 × 0.02 . = 4.38
Interest and depreciation on transformer = $81.00 × .10 . . . . . = 8.10
Interest and depreciation on station equipment chargeable to transformer = 0.230 (total full load losses in kilowatts × 150 × .10 . . . . . = 3.45
Total . . . $29.95

The selection of four hours equivalent full load copper loss in the above example was arbitrary, as also was the cost of power. In determining the equivalent full load copper loss, it must be born in mind that copper loss varies as the square of the load. For example, at half load we have one-quarter full load copper loss. As a further example, two hours at full load and four hours at half load, give the equivalent copper loss of three hours at full load. The interest and depreciation charge on station equipment should not be charged against the annual cost of operation of the transformer, if surplus station capacity exists or would be installed independent of any consideration of transformer losses. Again, a uniform rate of two cents per kilowatt hour for any hour of the day would not be correct if the transformer losses constituted a real check on the sale of power. That is, if there is a market for more power than is generated, so that the transformer losses cut out the sale of an equal amount of power, the cost of losses should be computed on the basis of a light load period of say, 20 hours per day at two cents per kilowatt hour, and on some other value, such as 4, 5 or possibly 6 cents per kilowatt hour during the peak of the load, say 4 hours; the peak load value being determined by what the central station manager feels his power at peak load is really worth to him. The above reasoning applies both to core and copper losses.

Transformer regulation is largely a function of the copper loss and cannot be neglected. It has a very decided bearing on the question of lamp life and uniformity of light from the lamps connected to the transformer.

The heating of a transformer and its capacity for overload are of extreme importance to the purchaser, as the output of the transformer is directly limited by its heating; due consideration being given to uniformity of heating and the ability of the insulation to stand a certain degree of heat as contrasted with other classes of insulations, which break down or deteriorate at lower temperatures. Exciting currents will be separately discussed.

(To be Continued)

CENTRIFUGAL AIR COMPRESSORS

By J. G. Callan

A new type of apparatus has somewhat recently become available for the delivery of compressed air of a fairly wide range of pressure and volume, the advantages of which are numerous and considerable. The machine referred to is the so-called "turbine compressor," or "centrifugal compressor," which is a development of a well-known centrifugal fan, but which, both in range and efficiency, greatly transcends anything previously accredited to centrifugal apparatus. A parallel-flow turbine type of compressor, analogous to the Parson's turbine reversed, is also on the market and is used to some extent in Europe, but has met with little success in America.

Air for industrial purposes is now customarily supplied by four types of apparatus, adapted in the following order to pressures ranging from the lowest to the highest; namely, the propeller fan, the centrifugal fan, the rotary positive blower, and the reciprocating compressor. Each is governed by laws of its own, which influence its losses and determine its field of application, and it will be well to briefly review the principles of each as a preliminary to the consideration of new forms of air compressors which are primarily the matter of interest herein.

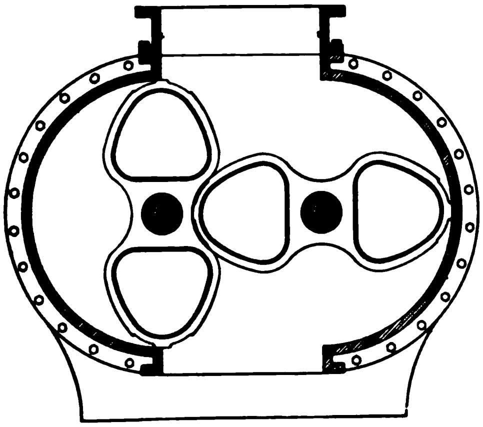

Fig. 1. Example of Cycloidal Type of Positive Blower

The propeller fan, which is familiar in the ordinary small electric fan and larger plate fans, has a rotating member or impeller of the type of a marine screw propeller. It is used only where relatively large volumes of air must be moved against practically no unbalanced head in excess of a moderate velocity head. This type of fan is principally used in the different systems of ventilation. Its efficiency is satisfactory where there is no unbalanced static pressure, but falls rapidly as this condition is departed from.

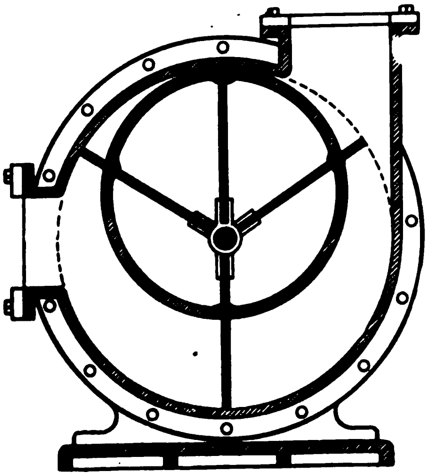

Fig. 2. Example of Wing Type of Positive Blower

The losses under most favorable conditions consist solely of blade friction and eddies. Where there is unbalanced pressure head, the higher pressure generated by the blade tips usually forces varying quantities of air backward through the central portion, with a resultant loss which soon becomes very serious. This type of apparatus has been made a subject of exhaustive study in connection with the design of propellers for flying machines.

The centrifugal fan is used to deliver air in widely varying volume, against pressures ranging from a fraction of an inch of water pressure to about 1 lb. per sq. in. Its uses are widely various, and include ventilation, transportation of light materials (such as cotton or shavings), forced or induced draught, and many minor applications. Losses result from choke, friction and throttling in passages, rotation, residual velocity, and leakage through impeller clearance. The efficiency for well designed types under favorable conditions is in the neighborhood of 50 per cent., being occasionally a little higher and often much lower.

Ordinarily, centrifugal fans for high pressures, with the high residual and rotation losses attendant in common designs, are relatively speaking disadvantageous and uneconomical.

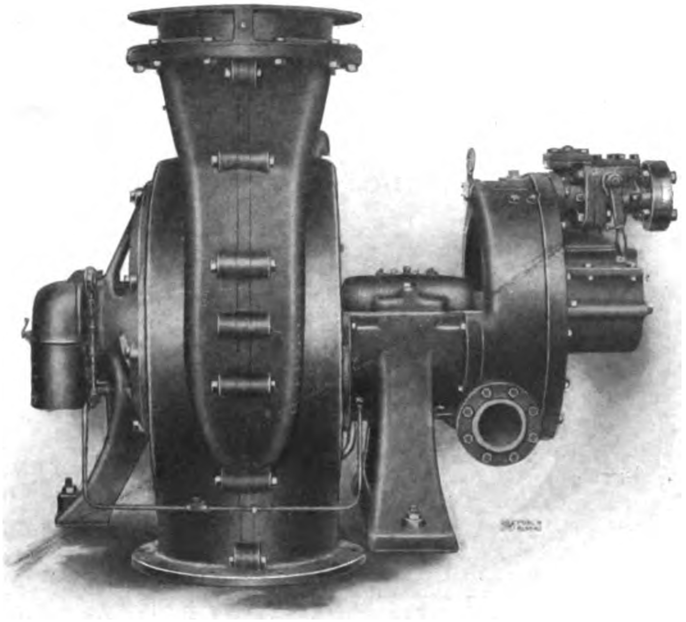

Fig. 3. Centrifugal Air Compressor, Direct Connected to Horizontal Curtis Turbine

The rotary positive blower is a machine in which air is trapped in chambers during each revolution, and positively forced out of these by the rotation of suitably designed parts. The most common form is analogous to the well-known gear pump, in which the engaging gears are each, in effect, a two-tooth pinion, made with rolled curves similar to those of all gear designs, and consequently meshing accurately with each other when revolved at constant velocity ratio. These gears are not suitable for driving each other, and hence ordinary spur gears are mounted on the shafts and perform this function. These impellers revolve in a casing, as shown in Fig. 1, and in the best designs are intended to maintain a slight but constant clearance between impeller and casing, and between each other.

Another form of positive blower is the wing type, which has many times figured in rotary engine patents. Several modifications of this type have been put forward, one of the best of which is shown in Fig. 2. It will be seen that in this machine the revolving wings are pivoted concentrically with the main casing, but are driven at variable velocity by the element which forms at once the driving member and the abutment against which the air is compressed. Other forms are built, particularly in smaller sizes.

No attempt will be made to analyze the losses of all forms of positive blowers. Considering only the cycloidal type described above, the losses may be divided into three groups: First, leakage through the clearances, usually known as slip; second, regurgitation, by which is meant the loss due to air from the discharge pipe returning into the pocket between impeller and casing as soon as the communication between the two is opened. On reference to the diagram, it will be seen that this pocket is filled, first with air at atmospheric pressure or slightly below, and then, without change of volume, put into communication with the discharge. The result is exactly what would occur if a reciprocating air compressor mechanically opened its discharge valves just as the piston started on the compression stroke. The card would obviously be rectangular instead of showing a compression line, or in other words, a certain proportion of the air would have to be delivered twice against full pressure. This loss becomes considerable as the delivery pressure rises. Its percentage value is approximately one-half of the rise in pressure divided by the final pressure.

The third group of losses is due to friction, consisting in general of: (a) impeller friction (sides and ends); (*b*) bearing friction; (*c*) belt or gear-drive friction; (*d*) friction between gears driving second impeller from the directly driven shaft; (*e*) air friction and throttling at last stages of filling pocket. With this last may conveniently be considered the heating of indrawn air, which is slight.

A great deal of work has been done in determining the value of these losses, and particularly of the slip, but comparatively little published data are generally available. Figures for volumetric efficiency, which should be high, are often mistaken for figures upon net or shaft efficiency, which is necessarily much lower.

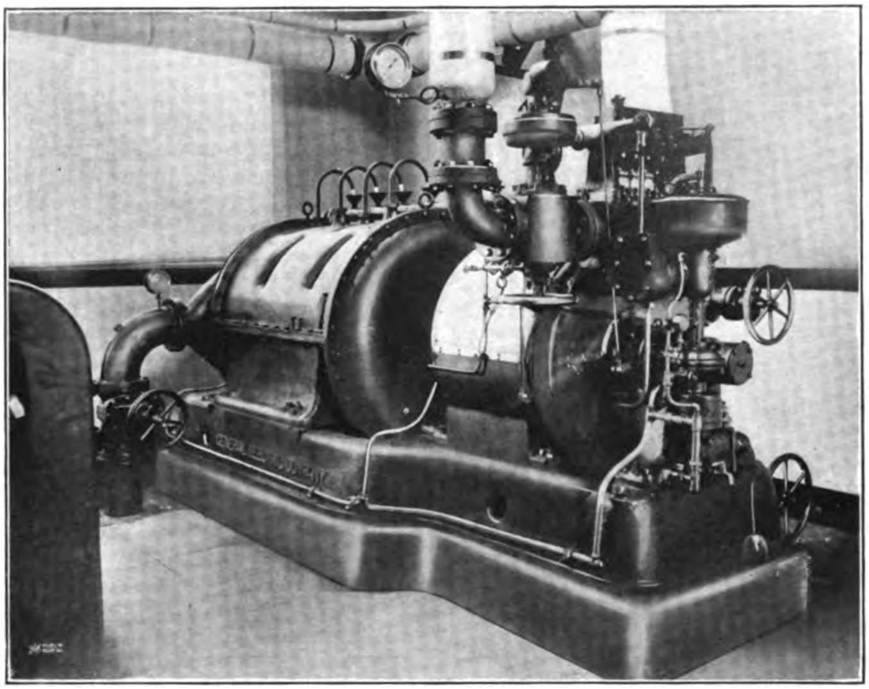

Fig. 4. Multi-stage Compressor driven by Horizontal Curtis Turbine

These blowers are used where pressures range between about ½ lb. and 5 lbs. per sq. in., although these limits are occasionally overstepped. Units are made in sizes from a fraction of a horse-power to 600 or 700 h.p., the latter being used principally for copper and lead smelting.

The reciprocating piston compressor is employed for pressures from about 3 lbs., or somewhat less, up to the highest air pressures ever employed. The sizes and types cover the widest possible range, and would require a treatise for a full description. With reciprocating compressors delivering air at low pressure, the drop of pressure in the valves becomes a very serious matter. Modern machines therefore have mechanically-operated valves which can assume widely varying forms. The Schlick valve, which has excited much comment, consists simply of an arrangement for moving the entire cylinder away from the heads, thus allowing a maximum inlet area.

Reciprocating compressors for very high pressures are generally arranged in stages with intercoolers and after-coolers which reduce the work of the compressors and the size of the pipe line required.

Applications of reciprocating compressors are too numerous to be listed here, and the designs range from bicycle pumps to blowing engines furnishing huge volumes of air for blast furnaces, or immense compressors for supplying high pressure air for pneumatic drills in mines.

The losses peculiar to high pressure compressors are outside the scope of this article. For low and moderate pressures, losses are: (*a*) leakages past piston, and inlet and discharge valves; (*b*) clearance loss; (*c*) throttling and heating of air at inlet; (*d*) throttling at discharge. We need not consider the loss due to heat of compression, since on low and moderate pressures, adiabatic compression is usually taken as standard. For higher pressures, this is not the custom.

The design of centrifugal or "turbine" types of air compressing apparatus for pressures very much in excess of those formerly thought possible, has recently been taken up by several independent investigators. This investigation is analogous to that which has resulted in the recent production of centrifugal pumps of high pressure, capacity and efficiency, and work has been along somewhat analogous lines.

The field to which these centrifugal compressors will at first be confined is, broadly speaking, between pressures of one pound and thirty pounds per sq. in. The corresponding available volumes vary with the pressure, since with higher pressure it is not advantageous to construct small units. Roughly, the smallest practical horse-power for pressures up to 25 lbs. gage, is approximately (gage pressure)^2 + 5. Such a line of apparatus must possess commercial advantages to justify its development, and these lie in its simplicity, durability, absence of depreciation, compactness, and small size, as compared with apparatus now standard. Efficiencies are in general about the same as or slightly above those of standard competing apparatus.

Where pressures in excess of 4 or 5 lbs. per sq. in. are required, several centrifugal stages in series are used, each adding its quotum to the resultant pressures.

It is expected that there will be many applications for such apparatus, but the principal ones may be grouped as follows:

Combustion. Excluding metallurgical processes, this consists in delivering air for gas and oil furnaces, and under exceptional conditions for coal furnaces, although the latter generally use much lower air pressure, except where the fuel is powdered. Pressures ranging from the lowest available to some 15 lbs. are those usually met with the average oil fire requiring about 2 lbs..

Metallurgical Processes. The smelting of lead and copper requires large volumes of air at pressures ranging from 28 ounces to 60 ounces, and in this field the cycloidal blower has been pre-eminent. In smelting it is usually necessary to hold volume rather than pressure constant, and the centrifugal compressor, which inherently holds constant pressure when the speed is constant, must be provided with a suitable air actuated governor for varying the speed when used for this purpose. This is readily done.

In blast furnaces the reduction of iron from ore takes pressures averaging 15 lbs., but ranging considerably above and below this value for different furnaces, or for the same furnace at different times. A multistage compressor of large proportions is required, and here again it is usually necessary to hold volume constant by means of an air-actuated governor.

The ordinary cupola, which is a small simplified and modified blast furnace, requires pressures around 14 ozs., and may be operated either on constant pressure or constant volume. In either case, the centrifugal compressor gives excellent service.

Gas Works and by-product coke ovens often employ compressors well within the range of the centrifugal type. Air is used for blowing the water-gas producers; gas must be forced through by-product apparatus, such as washers, scrubbers, etc.; and again, gas pressure often requires to be "boosted" for the supply of outlying districts, or for the transfer of storage from one gas holder to another. In addition, gas producers of both suction and pressure type occasionally employ blowers to maintain constancy of operating conditions. A special application is a centrifugal gas washer and tar extracter.

Transportation of bulk materials such as ashes and grain, and the carrying of mail and cash carriers in pneumatic tubes, affords an excellent field. The simplicity and compactness of the centrifugal units, coupled with their ability to operate under adverse conditions and their comparative immunity from injury due to passage through them of small foreign substances, renders them admirably suited for such service.

There are many other miscellaneous applications to which the characteristics of the centrifugal compressor well adapt them, such as ventilation and air-cooling, where relatively high pressure is necessary; breaking up scum on filter beds; and the agitation of vats, etc.

It is the belief of engineers familiar with the subject that this type of air compressing apparatus will have a very wide field of usefulness in the immediate future, and that it represents one of the most notable of recent mechanical developments. An article describing some technical details of centrifugal compressors will appear in the next issue.

GENERAL ELECTRIC REVIEW

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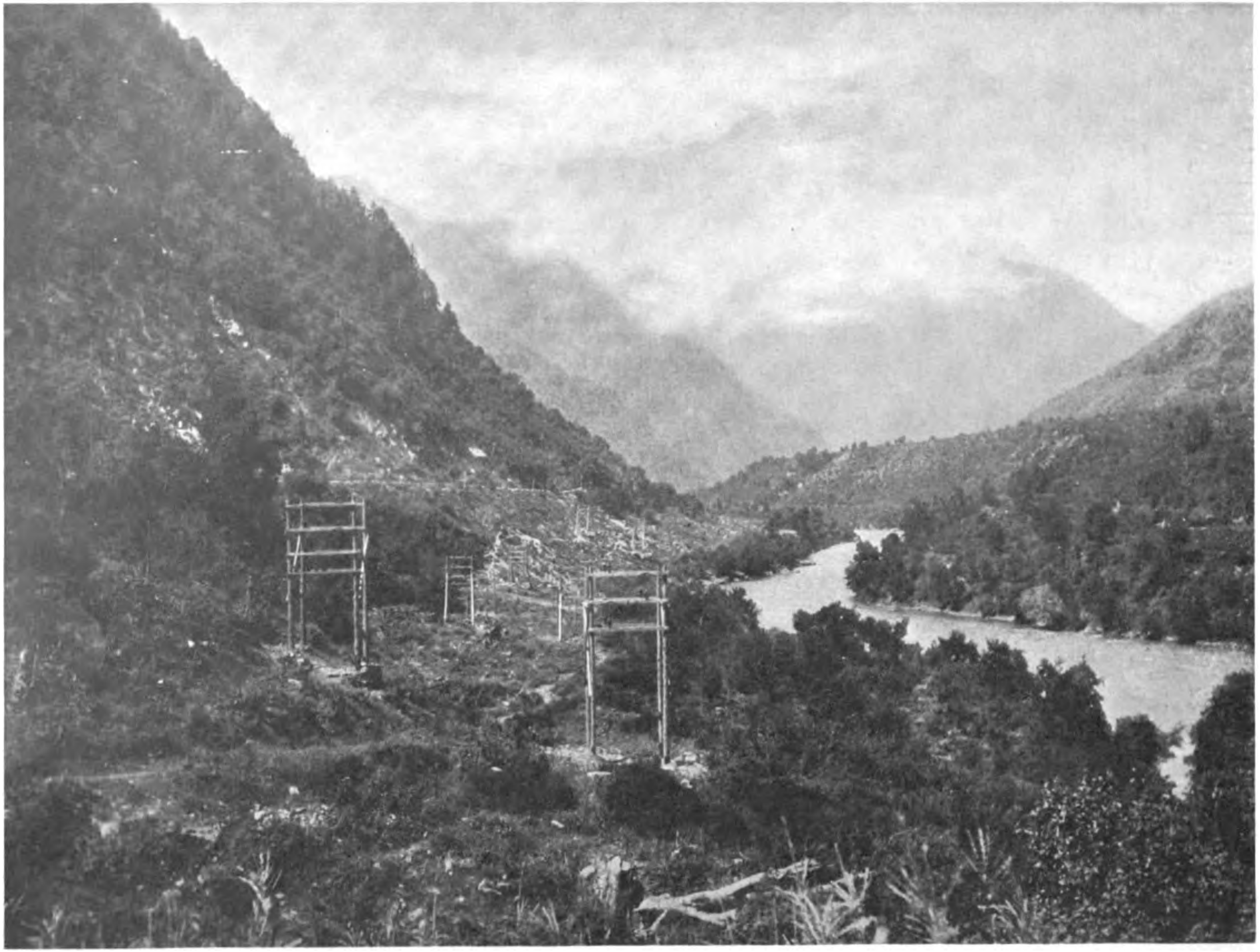

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GENERAL ELECTRIC REVIEW

DIRECT CURRENT SERIES MOTORS

The rapid and enormous development of the electrical industry was largely brought about by the success of the series direct current railway motor. The extensive application of this type of motor in traction work makes its study of much importance, and the article by Prof. F. B. Crocker and M. Arendt, beginning in this issue of the Review, is therefore of special interest.

Although the series motor is simple in its conception and arrangement of parts, the railway type, owing to unusually severe service conditions, has taken years to develop to a high state of perfection. The problem has been to assemble in a restricted space electrical and mechanical parts of minimum weight that would operate with high efficiency and almost perfect reliability under the most adverse conditions.

Fortunately, though largely by chance, a voltage was selected almost at the beginning of traction work which has proven well adapted for general service. Considering the early knowledge of the art of motor and equipment design, power transmission, insulating problems, etc., probably no potential could have been selected which would have been preferable to 500 volts. Increased knowledge has made higher potentials possible, but it is doubtful if development would have been so satisfactory had a higher or lower voltage been selected in the beginning.

The introduction of commutating poles has made marked improvements in commutation possible, and has rendered it comparatively easy to design successful motors for 1200 volts and higher.

Railway motors are designed to meet a great variety of conditions, no two problems being exactly alike. Theoretically, to give highest efficiency each problem should be met by a special design of motor; in order to have the most economical distribution of losses, as between I^2R, iron and friction losses. Under service conditions which demand frequent and rapid acceleration, a motor should have low I^2R loss, less consideration being given to core loss. For free running with infrequent stops, iron losses become relatively more important.

As influencing economy of operation, the shape of the speed curve is important, a characteristic which will give high torque per ampere in starting and maximum free running speed being well adapted for acceleration work. This type of machine would naturally be one in which the magnetic densities were low, with a minimum number of turns in the field coils. A machine of this type, if of extreme design, would, however, be unstable in commutation with resultant flashing and rough wearing of commutator. Generally speaking, a machine of high saturation, while somewhat less efficient, may operate with greater all-around satisfaction.

E. D. Priest

CENTRIFUGAL AIR COMPRESSORS

The large increase in the use of centrifugal pumps in recent years, and the very much larger increase in the use of steam turbines, make any new development of centrifugal machines, which are peculiarly suitable for turbine drive, especially interesting. While centrifugal blowers have been in use for many years, the scientific development of centrifugal compressors for producing a considerable pressure of air, is comparatively recent. The successful results that have already been obtained by these machines, made at Lynn, adds to the importance of the article in this number of the Review by Dr. Moss, who has been actively engaged in the compressor development.

When pumps and compressors were principally operated by reciprocating engines, it seemed natural to use reciprocating pumps and compressors, but the development of electric motors has added an impetus to further developments of rotary apparatus, and the more recent commercial development of steam turbines has carried this effect to machinery of large capacity.

The very small number of rubbing surfaces involved in the centrifugal compressor, as well as the small amount of space and weight involved, tending to a smaller first cost of manufacture and installation, and to a greater reduction in cost of maintenance, should lead to a very extensive use of these machines. A great deal of careful scientific investigation and experimental work has been devoted to the centrifugal compressor. Centrifugal pumps and fans are by many considered to involve only a question of centrifugal force, but it has been shown that the "nozzle action" for conversion of pressure and velocity is of extreme importance.

The measurement of air is a difficult matter and there is much difference of opinion as to the proper way of accomplishing this; it is hoped that the American Society of Mechanical Engineers will recommend some method to be followed. This is of especial importance because different methods are now being followed by various manufacturers, and one of the government departments has adopted still another.

MAXWELL W. DAY

HARD DRAWN COPPER WIRE

The American Society for Testing Materials is one of the most active of the technical societies, and it is fast becoming the recognized clearing house for all questions pertaining to the testing of materials and to the standardization of specifications for materials. Work of this character is undertaken by the Society through technical committees, appointed from its membership; and by the rules of the Society, such technical committees are required to consist of approximately equal representation of producing and consuming interests; the chairman of the committee in all cases being a consumer. It is the effort of the Society to have not individuals but representatives of producing and consuming companies on their technical committees.

In the REVIEW of August, 1908, there was published a paper on the desirability of standard specifications for hard drawn copper wire which was presented before the Society at their annual meeting in 1908. At that time, the Executive Committee of the Society was requested to consider the desirability of creating a committee having for its object the preparation of specifications covering hard drawn copper wire. Favorable action was taken by the appointment of Committee "W," with the following membership:

American Brass Co. (Mr. W. H. Bassett).
American Steel and Wire Co. (Mr. J. F. Tinsley).
General Electric Co. (Mr. J. A. Capp, Chairman).
J. A. Roebling's Sons Co. (Mr. H. J. Horn).
Standard Underground Cable Co. (Mr. C. C. Baldwin).
Viele, Blackwell and Buck (Mr. O. A. Havill).
Waclark Wire Co. (Mr. F. W. Wallace).
Western Electric Co. (Mr. C. Crosland).
Westinghouse Elec. and Mfg. Co. (Mr. T. D. Lynch).
J. G. White and Co. (Mr. C. D. Gray).

This committee presented its report to the Society at the annual meeting held at Atlantic City, June 29th to July 3rd, 1909, and the proposed specifications which were included in the report were, without dissent, referred for letter ballot by the Society as a whole.

When a committee reports with reasonable unanimity, the Society usually submits the specifications to the members by ballot, and they are generally approved. In this case they are recommended for general use in the trade with full confidence; as they have been thoroughly considered and carefully adjusted to commercial conditions by the producing and the consuming interests composing the Committee.

Committee "W" appended to its proposed specifications certain explanatory notes, giving the reasons for the omission of some requirements which have been included in many specifications upon hard drawn copper wire, and for the inclusion of other requirements. Since the Committee is a representative one and their action in recommending the proposed specifications to favorable consideration by the American Society for Testing Materials was unanimous, it may confidently be expected that the letter ballot by the Society will be favorable. The specifications themselves, together with the explanatory notes, are therefore published in this issue.

These specifications have already been adopted as standard by the members of Committee "W", and their adoption by the trade in general is strongly urged. The manufacturers of hard drawn copper wire feel that they will be able to turn out a much more uniform product if they can work under one uniform specification, instead of having to meet the requirements of a large number of specifications which differ in their requirements only enough to cause confusion in the mill, or which impose conditions difficult if not impossible to meet.

DIRECT CURRENT SERIES MOTORS*

Part I

By Prof. F. B. Crocker and M. Arendt

Series motors are of two general types, constant potential and constant current. Attention will be paid chiefly to the former, since the latter are no longer used commercially. The greatest of all applications of the electric motor is to electric traction, for which service series motors are almost universally used in this country. It is logical, therefore, to discuss the action and control of series motors from the railway standpoint, although their application to hoists, fans, pumps, etc., is also important.

As the name of this motor implies, the field and armature windings are in series, Fig. 1, hence the current that flows through the armature also excites the field magnet.

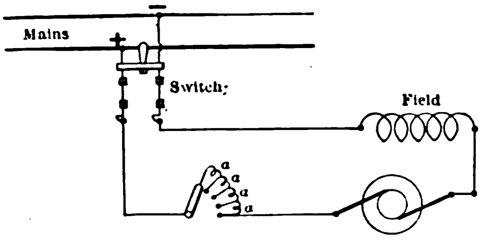
Speed Current Curve

The speed of a series motor rises when the current is diminished, the exact relation depending upon the degree of magnetization of the magnetic circuit. At low current values, and therefore low flux densities, the speed is relatively high and the amount of its variation for a given change in torque is correspondingly great. The speed is much lower and more nearly constant when the field approaches saturation. The formula for the speed of a motor is:

$$r.p.m. = \frac{E\ 10^8\ 60\ b}{N \Phi 2p}$$

The flux Φ is the only variable and depends upon the field current in the case of a series motor, being the same as or proportional to the armature current. The flux at low densities increases almost proportionally with the current and if there were no voltage drop due to resistance, the *speed current curve* would take the form $r.p.m. \times \Phi =$ Constant, which is an equilateral hyperbola, asymptotic to both co-ordinate axes. However, as saturation of the magnetic circuit is approached there is a gradual reduction in the rate of increase of flux with current, thus flattening the lower portion of the curve. This relation between speed and amperes input is brought out numerically in the two following examples. The first assumes a series motor (A) with a field of relatively low flux density; and the second, a series motor (B) of equal current capacity but having a field approaching saturation below rated load.

The series motor (A) is assumed to run on 550-volt constant potential circuit, its armature resistance being 0.7 ohm and field resistance of the same value. This motor, operated as a dynamo (separately excited) at a constant speed of 200 r.p.m., gives, in terms of voltage generated, the magnetization curve A in Fig. 2, with field current variations from 0 to 50 amperes. Armature reaction may be practically neglected, being relatively small in series machines since the brushes are in the neutral position and because field m.m.f. rises with armature current and m.m.f. Brush drop is also a practically negligible item in most series motors which run at 550 volts or more in railway service and usually at voltages of 240 or higher for stationary work. Moreover, the field winding being in series with the armature, drop due to resistance is about twice as great as in a shunt machine of the same voltage, making brush drop relatively small, and it will be considered as included with the armature drop.



Starting and Regulating Rheostat

Fig. 1. Connections of Series Motor

The speed-current curve is calculated as follows:

At five amperes input the voltage drop due to armature and field resistance is $I\ R_a + I\ R_{se} = 5(.7 + .7) = 7$ volts, hence the counter e.m.f. generated with 550 volts applied $= 550 - 7 = 543$ volts. From Fig. 2, curve A, the field flux due to 5 amperes produces at 200 r.p.m. an e.m.f. of 56.5 volts; hence to develop a counter e.m.f. of 543 volts, the r.p.m. $= (543 \div 56.5) \times 200 = 1920$. The speed at other torque conditions corresponding to 10, 20, 30, 40 and 50 amperes can be similarly calculated; the results being given in the following table.

---

* This article will appear later in a text book

CURRENT-SPEED DATA SERIES MOTOR A (LOW FLUX DENSITY)

Amp.	*V.*	I_aR_a	I_aR_{se}	*counter e.m.f.* = $V - (I_aR_a + R_{se})$	*Volts at 200 r.p.m. Curve A., Fig. 2*	*R.p.m.* = $\frac{\text{counter e.m.f.}}{\text{Volts at 200 r.p.m.}} \times 200$
5	550	3.5	3.5	543	56.5	(543 ÷ 56.5)200 = 1920
10	550	7.0	7.0	536	108.0	(536 ÷ 108)200 = 1155
20	550	14.0	14.0	522	200.0	(522 ÷ 200)200 = 522
30	550	21.0	21.0	508	283.0	(508 ÷ 283)200 = 359
40	550	28.0	28.0	494	350.0	(494 ÷ 350)200 = 283
50	550	35.0	35.0	480	412.0	(480 ÷ 412)200 = 233

Plotting these speed and current values in the form of a curve (a) Fig. 3, and comparing the various values, it is seen that the speed varies greatly with the current, the range being from 1920 to 233 r.p.m. with currents from 5 to 50 amperes.

In the case of series motor B, the armature and field resistance are 0.4 and 1.0 ohm respectively, and the magnetization-voltage curve of this machine operating at 200 r.p.m. with 5 to 50 amperes field current is curve b, Fig. 2, showing much higher flux densities than curve a of the first machine. The rated load current is 50 amperes and line pressure 550 volts as in the case of motor A. The relations existing between current and speed can be calculated as in the preceding case, the results being given in the table below.

The effects of low and high magnetic flux densities on the speed of series motors at various loads is shown by the speed-current curves in Fig. 3. The type of direct current series motors commonly employed is that with the higher flux density on account of the greater economy of material and better operation under conditions of variation in the line voltage.

Comparing the speed curves of series and shunt motors (Fig. 4) it is apparent that the speed changes in series motors are due, not only to $I_a(R_a + R_{se})$ effects, but more especially (up to heavier loads) to increase in field strength. The IR_a drop is greater in series than in shunt motors of the same rating, because the former are usually designed for intermittent service, so that the current density in the field and armature windings can be made much higher than would be

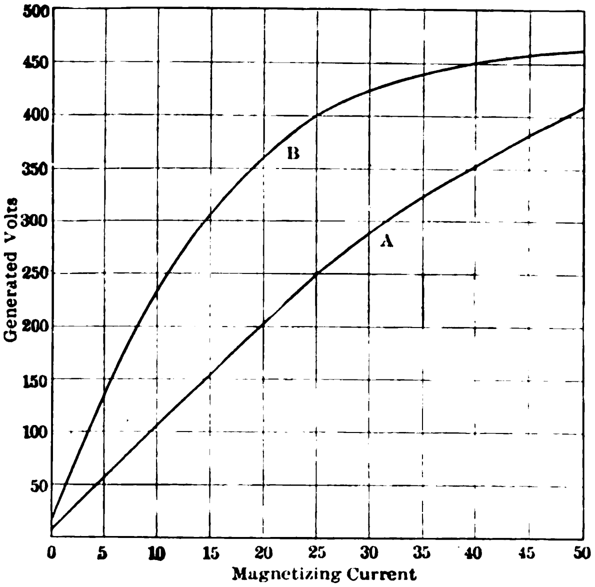


Fig. 2. Magnetization Curves of Series Motors, A and B

CURRENT-SPEED DATA SERIES MOTOR B (HIGH FLUX DENSITY)

Amp.	*V.*	I_aR_a	I_aR_{se}	*counter e.m.f.* = $V - (I_aR_a + R_{se})$	*Volts at 200 r.p.m. Curve B., Fig. 2*	*R.p.m.* = $\frac{\text{counter e.m.f.}}{\text{Volts at 200 r.p.m.}} \times 200$
5	550	2	5	543	137	(543 ÷ 137)200 = 794
10	550	4	10	536	235	(536 ÷ 235)200 = 455
20	550	8	20	522	360	(522 ÷ 360)200 = 290
30	550	12	30	508	420	(508 ÷ 420)200 = 242
40	550	16	40	494	450	(494 ÷ 450)200 = 220
50	550	20	50	480	462	(480 ÷ 462)200 = 207

approved of in the shunt motors, which are usually loaded more continuously.

The speed for any given current, as already shown, depends upon the counter electro motive force generated, or upon $V - I(R_a + R_{se})$ hence the speed at any line voltage V_x is obtained from the equation:

$$r.p.m._x = \frac{V_x - I\ (R_a + R_{se})}{V - I\ (R_a + R_{se})}\ r.p.m.$$

where *r.p.m.* and *r.p.m.x.* are the speeds at the standard and fractional voltages respectively; V and V_x being these voltages, while $I(R_a + R_{se})$ is the resistance drop in the motor windings. When V_x is less than V, the speed corresponding to it is smaller than the ratio $\frac{r.p.m.\ V_x}{V}$ since the resistance drop is then a larger part of V_x than it is of V. Similarly when V_x is greater than V the reverse is true. When V_x is equal to $I(R_a + R_{se})$ the armature will stand still, exerting torque corresponding to I. For any increase in V_x above this value, the speed rises proportionately.

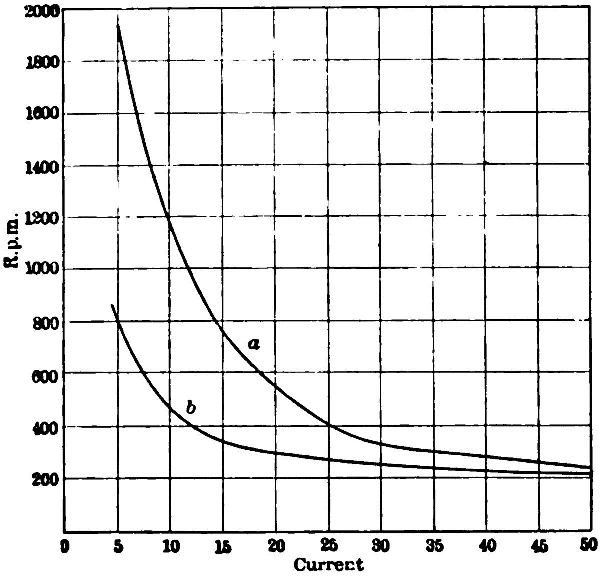


Fig. 3. Speed-Current Curves of Series Motors, A and B

The speed-current curves of a typical 200 h.p. railway series motor (G.E. Type 69 C—N. Y. C. "M. U." Trains) at 600, 300 and 150 volts, are shown in Fig. 5.

The curves for 150 and 300 volts have been calculated from the 600 volt curve given by the manufacturer, by means of the preceding speed-current equations.

Torque-Current Curve

The torque of any motor varies directly as the product of armature and field fluxes. Hence in a series motor the torque at low flux densities varies directly as the square of the current; that is, torque $= K\ I^2$; but as the magnetization approaches saturation the torque becomes more nearly proportional to the first power of the current.

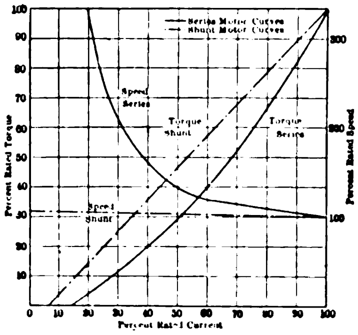


Fig. 4. Comparative Speed and Torque Curves of 100 H.P. Series and Shunt Motors

The torque of a series motor is independent of the voltage except for a variation in hysteresis, eddy current, friction and windage losses resulting from the change in speed with the altered voltage. At low voltages and corresponding speeds, these losses are reduced and the available torque per ampere is similarly increased; at higher voltages the reverse is true. Since the hysteresis loss varies as the first power, and eddy current loss as the square of speed, the difference in torque for any given current is greater between the 150 and 300 volt curves than between the 300 and 600 volt curves. The percentage difference between torque values at any two voltages increases with the current on account of ratio of speeds at these voltages. Fig. 5 shows the torque-current curve for the typical 200 horse-power series motor at 600 volts, being approximately correct for 150 and 300 volts also, because the variation in the losses is small compared with the total torque.

The constants change with the voltage, resistance, and degree of magnetization of the magnetic circuit. Fig. 9 gives the speed-tractive effort curves of the typical 200 h.p. motor at 150, 300 and 600 volts, the equations of which are:

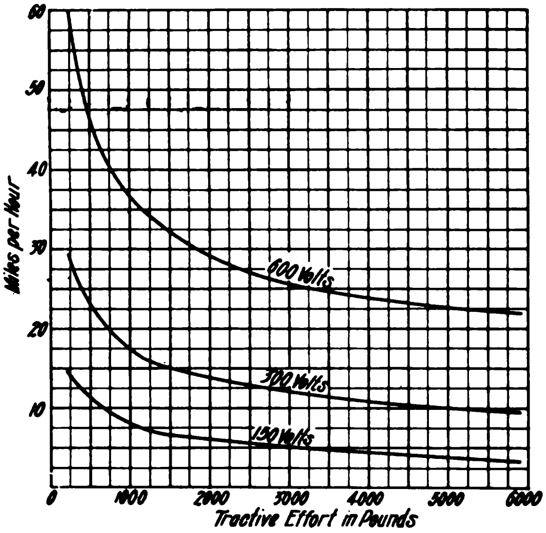


Fig. 9. Speed Tractive Effort Curves of a G.E. 69C Railway Motor

$$\text{At 150 volts, } t.e. = \frac{12{,}800}{m.p.h. - 1.82} - 970$$

$$\text{At 300 volts, } t.e. = \frac{25{,}300}{m.p.h. - 5.78} - 1050$$

$$\text{At 600 volts, } t.e. = \frac{35{,}800}{m.p.h. - 16.43} - 740$$

A number of points on the curves in Fig. 9 were derived by calculation and agree very closely with the test values over a wide range of speed.

Gears and Wheels

A railway motor is usually connected to the axle of the car drivers through a single pinion and gear, but in some cases the armature is directly mounted upon the axle of the car wheels. The speed and tractive effort at the rim of the driving wheels are respectively proportional and inversely proportional to the wheel diameter, while with gearing these two quantities are dependent upon the gear ratio which is always designed to secure speed reduction. The proper ratio depends upon the type of service to be performed, but usually lies between two and five, the lower value corresponding to high speed service. The effect of larger wheel diameter on tractive effort and speed is exactly the reverse of that obtained by increasing the gear ratio.

The speed and tractive effort for any gear ratio and wheel diameter may be found for any other known conditions from the following formulæ, wherein *m.p.h.* and $m.p.h._x$ are respectively the known and unknown speeds, in miles per hour for an existing gear ratio r and wheel diameter D. The gear ratio r_x and wheel diameter D_x correspond to the unknown speed $(m.p.h._x)$; T is the torque for the known gear ratio, and T_x is the corresponding unknown value:

$$m.p.h._x = m.p.h. \frac{r\,D_x}{D\,r_x} = \frac{.003\,(r.p.m.)\,D}{r_x} = \frac{.003\,(r.p.m.)\,D_x}{r}$$

$$T_x = T\frac{D\,r_x}{r\,D_x} = 24\,T r_x \div D_x$$

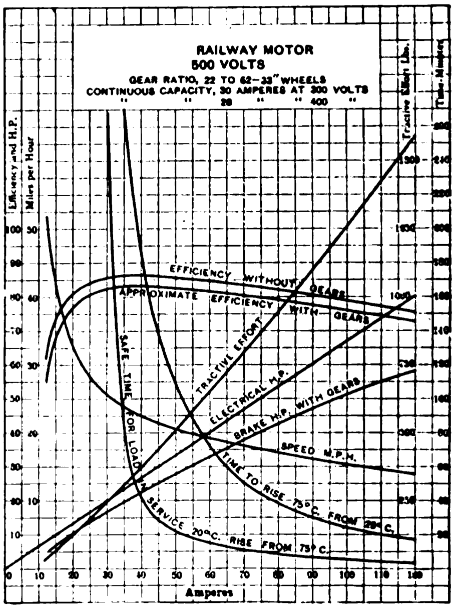


Fig. 10. Characteristic Curves of a Typical Railway Motor

The characteristic curves of a typical railway motor with gear ratio of 22:62 are shown in Fig. 10.

(To be Continued)

ALLOYS

PART I

BY JOHN T. H. DEMPSTER

The use of alloys dates back to the close of the stone age, when man fashioned his implements of war and the chase, such as knives, spears, axes, etc., from bronze—an alloy of copper and tin. This alloy has remarkable characteristics as compared with either tin or copper alone, from which elementary metals the earliest implements were made. The ancients were no doubt first attracted to copper by its beautiful red color, which, in its native state, would be very conspicuous in the rocks and streams; and, due to its low melting point and its ready submission to fire, masses of metal were obtainable from crude meltings, which were ductile and could be forged out with stone hammers into various forms. By this process of forging the metal took on additional hardness, and the result was implements which it would have been impossible to have fashioned from stone. The ancients were familiar with the white metal tin at an early date, the metal occurring in the beds of streams as the result of the disintegration of rocks; this native form now being known as stream tin. They no doubt soon found that its susceptibility to fire was greater than that of copper; but due to its lack of ductility and strength, it was not used alone to any extent. Very likely the discovery of the remarkable alloy resulting from a mixture of the two metals created considerable excitement at the time; for, with a good ratio of the metals, the alloy has the strength of steel, is tough, and will take a very keen edge. The art of making bronze spread all over Europe, and its use by the Peruvians in South America was wide. The Bible mentions the use of images and utensils of brass, but it is doubtful whether it is the zinc-copper alloy known by that name today. The making of alloys has been practised for ages by the Chinese and Japanese, and some of their products are noted for great beauty of color. Of these colored alloys they have a great number, which are ingeniously used together in layers of different thicknesses, the whole being welded into a single plate. The resulting sheet of metal is then fashioned into various forms, and by the skillful removal of different depths of the surface, splendid designs are formed of various colors. This work is very similar to the welded compound plates now being marketed, such as platinum or nickel on a heavy plate of steel or copper. Platinum on steel is now made into tubing and used for hypodermic needles; the steel giving the strength and the platinum the non-corrosive or non-oxidizable surface. The investigation of alloys is now being actively carried on, and, due to the larger range of elements available for use, the number of possible alloys seems limitless; it is almost safe to say that no pure metals are used to any extent today, as alone they lack some essential characteristic necessary for our purposes. Of the most common metals, iron is a good example. In its first commercial form, pig iron, it must contain considerable silicon to make it suitable for the ordinary grades of foundry iron, and for its conversion into steel by the Bessemer process. In the foundry cupola the silicon is the determining factor, to a large extent, of the ultimate form in which the carbon will be left in the iron—whether graphitic or combined. In the Bessemer process the combustion of the silicon effects a considerable saving of fuel, which in this case would really be iron. On the other hand, for making fluid irons, which give sharp impressions of the moulds, such as are used for stove work and for basic Bessemer steel, a pig iron high in phosphorous is required. In all forms of industrial iron, the carbon content is the important determining factor in its use. Carbon exists in iron combined in several ways, and also free as graphite; the carbon content varying from about 4 per cent. in cast irons, down to one-tenth of one per cent. in mild steels, or iron. Between the limits of this range come all the various qualities of steel, from a coarse car spring, or rail, to the finest watch spring or razor; the qualities of the metal being fixed by the content of alloyed carbon and its form, and the refinement to which the process of manufacture has been carried.

All of the wonderful results obtained from high speed (so called) and self hardening steels, are due to the skillful alloying of various quantities of chromium, tungsten, etc., with the iron; and the great molecular fatigue resisting properties conferred on steel by vanadium, and the high tensile strength gained by alloying nickel and chromium, have been quickly taken advantage of by makers of gas engines and automobiles, and has enabled them to reduce weight and gain strength and reliability.

Electrically, we are interested in the great advance recently made in the magnetic qualities of iron, by alloying silicon therewith, whereby the losses incident to the cyclic reversals of magnetism have been greatly reduced and non-aging qualities conferred on the iron, thus attaining a great increase of efficiency. While speaking of iron alloys it is interesting to note that Dr. Ames Van Welsbach has recently discovered that an alloy of about 3 per cent. of cerium with iron has the property of giving copious streams of sparks when filed or scratched, even with a knife. These sparks are white, and are hundreds of times more numerous than when flint and steel are used, and it is possible to light a gas jet a foot away from their origin.

Copper of high electrical conductivity, which we usually consider as very pure, must always contain a small quantity of copper oxide, else it cannot be worked in the mills, since it has not strength enough for rapid manipulation. A well known use of alloys is found in the coinage of all countries which practically consists solely of such metals; for example, gold with silver or copper, silver with copper, copper with tin. or nickel with copper. These alloys are usually used on account of their greater hardness and wearing qualities, also some of the Roman emperors added so much lead to the silver, for personal reasons—probably of gain—that the currency was debased, and in time was only accepted at a large discount.

Of the most important alloys that have a fixed place in the arts, I will mention brass, a zinc-copper alloy, which, when used in the form of castings, probably comes next to iron in importance, giving a non-corrosive material, easily cast and machined and of good strength. It is used for countless purposes, and is made in the form of rods, tubes, wire, sheet, etc. Of the bronzes, the old copper-tin alloy gives gun and bell metals and a range of alloys chiefly noted for their great strength. Aluminum, manganese and phosphorus, when added to copper, give bronzes of great strength combined with toughness and forgability; some of these alloys in the form of wire have tensile strengths of over 200,000 lbs. per square inch.

For electrical purposes, alloys have chiefly been used for their usually high specific resistances, immense quantities of german silver, a copper-zinc-nickel alloy, being used for rheostats. For large currents, cast iron in the form of grids, and high resistance iron are used; the latter being high silicon iron. The addition of tungsten to german silver gives an alloy having a very small temperature coefficient, and this alloy is used mainly for standard resistance. Manganin, a copper, nickel, manganese alloy is somewhat similar.

To be brief, an alloy can be made to have almost any possible single characteristic, developed to a high value, such as a zero or low expansion coefficient for heat; an alloy of this kind being nickel steel: or this coefficient can be made of the same value as that of any one of several glasses, thereby substituting the alloy for the expensive metal platinum for incandescent lamp leading in wires. The alloy can have extreme hardness, thus replacing the sapphire as a meter jewel; or it can resist acids and oxidation at continued red heat, thus replacing platinum and glass. The melting point can be made extremely high or low; in fact all of these qualities can be varied by means of the metals used for the alloy, and the ratios thereof, one to another.

Different values of maleability, ductility, tensile strength, elastic limit, and a great many other factors enter into the characteristics of an alloy, all of which go towards determining the ultimate value of the alloy in the arts, other than that for purposes of a resistance material. The quill pen was superseded by the steel point, chiefly because of the greatly lower cost and superior writing qualities of the latter. But the steel pen is made so cheaply now that we do not stop to consider its value when it is made useless through the quick corrosion by the acids of the ink, and it is discarded. The advent of the fountain pen made it necessary to have a non-corrosive pen with a permanent writing point. The manufacturers, therefore, had to turn to platinum or gold, and an alloy of gold and copper is now used for the purpose, the point being tipped by welding with two small pieces of the hard metal iridium. The latter metal gives the wearing qualities to the point, and the gold copper alloy the strength, flexibility, and acid resisting qualities necessary in the body of the pen. This illustration of the fountain pen point shows that an alloy could not be made to have all the necessary qualifications, combining the hardness necessary for the point; so resort was made to welding. This frequently happens, that after we have laid down all the desired characteristics which an alloy for a specific purpose is desired to have, we find that it is necessary to sacrifice one to gain in others. One of the alloys most difficult to develop was one to satisfy the field of electrical cooking and heating, and the various industrial purposes to which such devices have been put. The then available metals in the form of wire, etc., all lacked some essential feature necessary for success. Either the metal would not stand age—some wires did, in fact, fall apart while carried in stock on spools—showing the loose banding of the alloy, or the wire rapidly oxidized away through use, thus diminishing the cross section and ultimately causing it to burn out. Other wires would resist the action of heat, but did not in themselves have a sufficiently high specific resistance, thus entailing a large bulk of material in the form of the heating element and preventing the design of devices in which this element occupied an inconspicuous part. The desire of designers of electrically-heated cooking devices is to have the electrical element outlive the useful life of the vessel or device to which it is attached; but with such metals and alloys as were available up to a short time ago, it was practically impossible. The requirements which a perfect metal or alloy should meet were well known, but it was not deemed possible to ever obtain such a substance. It should not oxidize to an appreciably greater extent than platinum or gold, in order to insure long life; and it should have a high melting point, thus permitting a high operating temperature and securing a correspondingly high efficiency of conversion of electrical energy into heat. It should also have a high specific electrical resistance, thus permitting the unit to be of small size in comparison with the size of the device. This design would localize the heat at the desired place, from which its transfer to the proper point could be most readily and economically effected. Also, the alloy should be one that could be manufactured in large quantities, of uniform quality and sufficiently ductile and malleable to be made into the finest wires and thinnest sheets necessary to cover the present field, and that future designers of apparatus might demand.

In the second part of this article, it will be shown that in the metal calorite these necessary qualifications have been met to a degree not anticipated when the experimental development of the alloy was started.

PROPOSED STANDARD SPECIFICATIONS FOR HARD-DRAWN COPPER WIRE*

Material

1. The material shall be copper of such quality and purity that, when drawn hard, it shall have the properties and characteristics herein required.

Shapes

2. These specifications cover hard-drawn round wire, grooved trolley wire and hard-drawn cable or strand, as hereinafter described.

Finish

3. The wire, in all shapes, must be free from all surface imperfections not consistent with the best commercial practice.

Packages

4. (*a*) Package sizes for round wire and for cable shall be agreed upon in the placing of individual orders; standard packages of grooved trolley wire shall be shipments upon reels holding about 2500 lbs. each.

(*b*) The wire shall be protected against damage in ordinary handling and shipping.

Specific Gravity

5. For the purpose of calculating weights, cross-sections, etc., the specific gravity of copper shall be taken as 8.90.

Inspection

6. All testing and inspection shall be made at the place of manufacture. The manufacturer shall afford the inspector representing the purchaser all reasonable facilities to enable him to satisfy himself that the material conforms to the requirements of these specifications.

HARD-DRAWN ROUND WIRE

Dimensions and Permissible Variations

7. (*a*) Size shall be expressed as the diameter of the wire in decimal fractions of

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*Report presented at the Annual Meeting of the American Society for Testing Material, June 29 to July 3, 1909.

an inch, using not more than three places of decimals; *i. e.*, in mils.

(*b*) Wire is expected to be accurate in diameter; permissible variations from nominal diameter shall be:

For wire 0.100 in. in diameter and larger, one per cent. over or under.

For wire less than 0.100 in. in diameter, one mil over or under.

(*c*) Each coil is to be gauged at three places, one near each end, and one approximately at the middle; the coil may be rejected if, two points being within the accepted limits, the third point is off gauge more than 2 per cent. in the case of wire 0.064 in. in diameter and larger, or more than 3 per cent. in the case of wire less than 0.064 in. diameter.

Physical Tests

8. The wire shall be so drawn that its tensile strength and elongation shall be at least equal to the values stated in the following table. Tensile tests shall be made upon fair samples, and the elongation shall be determined as the permanent increase in length, due to the breaking of the wire in tension, measured between bench marks placed upon the wire originally 10 ins. apart. The fracture shall be between the bench marks, and not closer than one inch to either mark. If, upon testing a sample from any coil of wire, the results are found to be below the values stated in the table, tests upon two additional samples shall be made, and the average of the three tests shall determine acceptance or rejection of the coil.

Diameter, inches	Area, circular mils	Tensile strength, lbs. per sq. in	Elongation in 10 ins. per cent.
0.460	211,600	49,000	2.7
0.410	168,100	51,000	2.6
0.365	133,200	53,000	2.4
0.325	105,600	54,500	2.3
0.289	83,520	56,000	2.1
0.258	66,560	57,500	2.0
0.229	52,440	58,500	1.9
0.204	41,620	59,500	1.8
0.182	33,120	60,500	1.7
0.162	26,240	61,500	1.6
0.144	20,740	62,500	1.5
0.128	16,380	63,400	1.4
0.114	12,996	64,200	1.3
0.102	10,404	64,800	1.2
0.091	8,281	65,400	1.1
0.081	6,561	65,700	1.0
0.072	5,184	66,000	0.9
0.064	4,096	66,200	0.9
0.057	3,249	66,400	0.8
0.051	2,601	66,600	0.8
0.045	2,025	66,800	0.7
0.040	1,600	67,000	0.7

For wire whose nominal diameter is between listed sizes, the requirements shall be those of the next larger size included in the table.

Electric Conductivity

9. Electric conductivity shall be determined upon fair samples by resistance measurements at a temperature of 20° C. (68° F.). The wire shall not exceed the following limits:

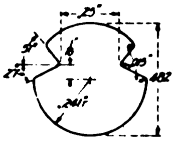
For diameters 0.460 in. to 0.325 in., 900.77 lbs. per mile-ohm at 20° C.

For diameters 0.324 in. to 0.040 in., 910.15 lbs., per mile-ohm at 20° C.

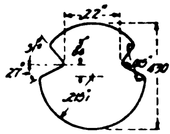
GROOVED TROLLEY WIRE

Sections

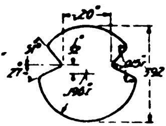
10. Standard sections shall be those known as the "American Standard" grooved trolley wire sections, the shape and dimensions of which are as follows:



211,600 C.M



168,100 C.M.



133,200 C.M

Dimensions and Permissible Variations

11. (*a*) Size shall be expressed as the area of cross-section in circular mils, the standard sizes being as follows:

211,600 c. m., weighing 3386 lbs. per mile.
168,100 c. m., weighing 2690 lbs. per mile.
133,200 c. m., weighing 2132 lbs. per mile.

(*b*) Grooved trolley wire may vary 4 per cent. over or under in weight per unit length from standard, as determined from the nominal cross-section.

Physical Tests

12. The physical tests shall be made in the same manner as those upon round wire. The tensile strength of grooved wire shall be at least 95 per cent. of that required for round wire of the same sectional area; the elongation shall be the same as that required for round wire of the same sectional area.

Electric Conductivity

13. The requirements for electric conductivity shall be the same as those for round wire of the same sectional area.

HARD-DRAWN COPPER WIRE CABLE OR STRAND

Construction

14. For the purposes of these specifications, standard cable shall be that made up of hard-drawn wire laid concentrically about a hard-drawn wire center. Cable laid up about a hemp center or about a soft wire core is to be subject to special specifications to be agreed upon in individual cases.

Wire

15. The wire entering into the construction of stranded cable shall, before stranding, meet all the requirements of round wire, hereinbefore stated.

Physical Tests

16. The tensile strength of standard cable shall be at least 90 per cent. of the total strength required of the wires forming the cable.

Brazes

17. Brazes, made in accordance with the best commercial practice, will be permitted in wire entering into cable; but no two brazes in wire in the cable may be closer together than 50 ft.

Lay

18. The pitch of standard cable shall be not less than 12, nor more than 16, diameters of the cable. The cable shall be laid left-handed or right-handed, as shall be agreed upon in the placing of individual orders.

EXPLANATORY NOTES ON THE PROPOSED SPECIFICATIONS

5. The specific gravity of copper has been commonly accepted as 8.9, and this value is retained in the proposed specifications. The maximum variation from this figure in a large number of samples of wire has not been sufficient to lead one to anticipate any serious error from its use as a flat value in calculations.

7. (*a*) The use of arbitrary gauge numbers to express dimensions cannot be too strongly condemned. There are many such gauges in existence, and confusion is to be expected unless the particular gauge to be used is specified. Many of the gauges have their dimensions stated in absurd figures, such as 0.090742 in., when it is not especially easy to measure dimensions in the fourth decimal place by workshop tools. Definite diameters in measurable units are evidently preferable.

8. Many other physical tests than those provided in these specifications are included in existing specifications. The reasons for the omission of some of the more common are given as follows:

Twist Tests.—The wire is sometimes required to permit twisting through a stated number of revolutions before breaking. The results are so easily influenced by temperature, speed of rotation, method of gripping and other variables not easily defined or controlled, that the test is at least of doubtful value. It is the opinion of the Committee that it is impractical to so define the conditions of the test that a twist test can be made definite and reliable; hence there is no warrant for its inclusion in specifications.

Wrap Tests.—Wire is sometimes required to permit tight wrapping about a wire of its own diameter, unwrapping and again re-wrapping. It is obvious that the making of a test of this kind with wire that is already hard-drawn is exceedingly difficult. Every one who has tried to break off a piece of tough wire by bending it back and forth between the fingers knows how hard it is to confine the bend to one place, because of the hardening action of the previous bends. Hard wire which has been wrapped around a wire of small diameter is hardened still more and it is almost impossible to straighten the wire, let alone re-coil it in the opposite direction. In the opinion of the Committee, it is inadvisable to include a test which at best is so indefinite as a wrap test. Furthermore, it is the opinion of the Committee that wire which will meet the physical tests included in the proposed specifications will meet any properly made twist or wrap test that would reasonably be required.

Elastic Limit.—During the tension test on wire, there is seldom to be observed any definite drop of the beam or increase in the rate of elongation, corresponding to the yield point commonly observed in testing steel. The only way in which the elastic limit of hard wire may be determined is by the actual plotting of the elastic curve from extensometer readings. Even such tests are difficult of interpretation, because the wire when available for tests is usually curved, due to its having been put up in a coil. There are little sets observable before the true elastic limit has been reached, owing to the fact that one side of the wire, having been stretched in coiling, is really a little harder than the other side, and the pull is, therefore, not even. Considering the difficulty of making the test and the uncertainty of the results obtained, it is the opinion of the Committee that it would be inadvisable to include an elastic limit test in the proposed specifications. It is evident that if the designing engineer requires a knowledge of the location of the elastic limit for purposes of calculation in designing, such data can be obtained by special tests on representative sizes of wire, which will fix the relation of the elastic limit to the ultimate strength for all wire which is properly made.

Elongation.—Elongation tests on wire are required in different specifications to be measured in lengths varying from 8 to 60 ins.

The elongation has variously been measured as the permanent increase in the length of the wire, measured between bench marks placed on the wire before fracture; as the elongation measured between the jaws of the testing machine, which are adjusted to grip the wire with a certain definite free length, and in various other ways. Perhaps the most commonly used length is 10 ins., and it is a good length, because measurements may be immediately transposed into percentages without laborious calculation. Measurement of elongation in any other way than as the permanent increase in length between bench marks, in the manner customary in the measurement of elongation of steel specimens, is open to criticism. If measurements are made between the jaws of the testing machine, there is included a certain amount of elongation which has taken place within the jaws, because the wire in stretching will have been reduced in diameter and, therefore, have stretched to a greater or less extent within the jaws themselves. If the measurement is made between bench marks on the wire just prior to breakage, there is included in the elongation a certain amount of elastic deformation.

9. Electric conductivity is usually expressed as a percentage on the Matthiesen basis, reference being made to determinations of the electrical resistivity of supposedly pure copper by Matthiesen, about 1865. Since that time the methods of refining copper have greatly improved, so that today it is not uncommon to find copper of over 100 per cent. conductivity on the Matthiesen basis. Furthermore, what the electrical engineer requires is that the wire shall not exceed a certain maximum electrical resistance. It seems obvious that it is less laborious to express quantities in direct definite terms than by reference to something else which requires interpretation before the results are ready for use in calculation. Resistivity is commonly expressed in a number of different ways, all being equivalent to the resistance of some unit of cross-section, this unit being expressed either in linear dimensions or as a combination of weight and dimensions. For convenience we give a table of equivalents of the values for electrical resistance included in the proposed specifications. The values are equivalent respectively to 97 per cent. and 96 per cent. conductivity on the Matthiesen basis.

900.77 lbs. per mile-ohm is equal to:
0.15776 ohms per meter-gram,
1.7726 microhms per centimeter-cube,
0.69789 microhms per inch-cube,
10.663 ohms per mil-foot.

910.15 lbs. per mile-ohm is equal to:
0.15941 ohms per meter-gram,
1.7911 microhms per centimeter-cube,
0.70517 microhms per inch-cube,
10.774 ohms per mil-foot.

10. It is obvious that the simplest designation of irregular shapes of similar outline is by sectional area, and the most commonly used unit among electrical engineers is the circular mil. Therefore, while the sizes of grooved trolley wire regularly used are generally known by B. & S. gauge number, corresponding to their sectional area, it has been deemed advisable by the Committee to list these sizes, in specifications, by their sectional area expressed in circular mils. The three sizes which are most extensively used commercially are the only ones listed; a fourth size is but little used, and the use is growing less.

11. The only way in which gauge variations are easily determinable in irregular shapes is by recourse to weights of standard lengths, and this has been the method adopted in the specifications.

14. So many variations in the construction of cable are possible that it has been deemed inadvisable to complicate the specifications by including requirements for any other than the one type most commonly used.

16. Physical testing of cable is at best a difficult matter, and the measurement of elongation in cable which has been subjected to a tensile test is uncertain, since it includes both the elastic deformation of the cable as a spring, the actual elongation of the wires and perhaps even some elastic deformation of the wires as such. It is, therefore, thought inadvisable to include a requirement covering an elongation test.

17. The permitting of brazes in wire entering into the construction of copper cable was discussed at considerable length, and it is finally the opinion of the Committee that, provided no two brazes are closer together than 50 ft., the cable has fully 90 per cent. of the theoretical strength obtained by adding together the required strengths of the constituent wires. This is due, in such long lengths, to the frictional gripping of the wires in the cable. The construction of long lengths of cable without brazes is costly, and it has been thought best, therefore, to permit their use, provided they are sufficiently widely spaced as not to be detrimental to the strength of the cable.

SERIES AND MULTIPLE CUT-OUTS ABSOLUTE AUTOMATIC TYPES

By P. S. Bailey

During the very earliest period of arc lighting, cut-outs were found to be a necessary adjunct, both for the personal safety of the trimmer, and to secure uninterrupted service by making possible the handling of suspended lamps while current remained on the supply circuit. In modern installations the number of lamps used per circuit has steadily increased, and it recently became apparent that the development of a satisfactory automatic absolute cut-out was imperative.

Fully realizing the situation, the General Electric Company has developed devices of this nature for both series and multiple circuits that have proved most satisfactory. These cut-outs are known as the Forms "J" and "K."

Fig. 1 shows a view of the Form J series automatic cut-out suspending a Form 3 d.c. series luminous arc lamp at the "on position," while Fig. 2 is a facsimile of the same device with the line short-circuited and the lamp connection absolutely broken by the removal of the lower or lamp suspending portion of the cut-out.

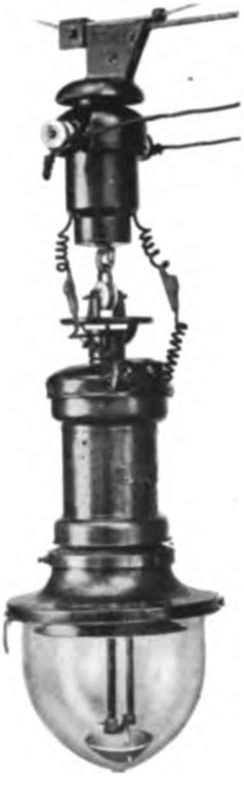


Fig. 1. Form J Series Automatic Cut-out, Suspending a Form 3 D.C. Series Luminous Arc Lamp Lamp in Circuit

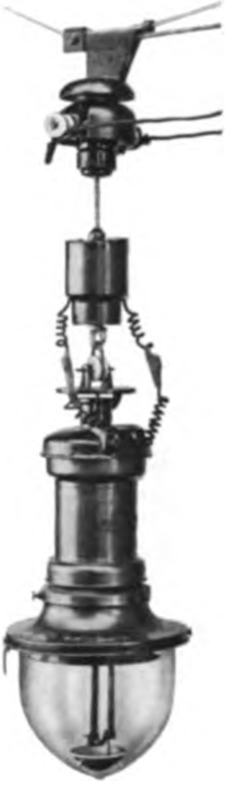


Fig. 2. Showing the Cut-out and Lamp with the Lamp Disconnected from the Circuit

It will be seen that the device is equipped with a special pulley fitting, and a stationary casting containing suitable cross-arms, porcelain insulator, short-circuiting ring, line contacts, and a lock-socket which constitutes the upper or top section. The section which can be lowered and which, in addition, supports the lamp, consists of a cylindrical vitrified porcelain insulator, chocolate brown in color, to which a lock carrier and movable lock-bolt are attached. The insulator is also fitted with a suitable lamp supporting hook at the bottom. Provision is made for the lamp leads, and the lowering and guiding cable is arranged in such a manner that there can be no possibility of a failure to properly lock, or of a reversal of polarity. When the lamp is raised the lock-bolt, which is of unique design and located in the lower section, engages the lock-socket in the upper section, thus effectually and safely holding the lamp in position. The device is easily unlocked by simply raising the lower section by pulling firmly on the rope, thus allowing the lock-bolt to disengage itself from the socket, and by paying out on the cable in the usual way. Connections from lamp to line are made by means of cast ring contacts, and the circuit is automatically closed when the lamp is removed therefrom.

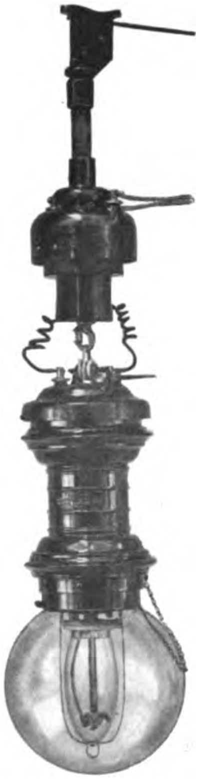


Fig. 3. Form K Multiple Automatic Hanger, Suspending a Form 12 D.C. Multiple Lamp. The Lamp in Circuit

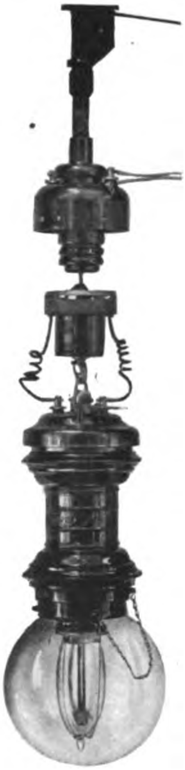


Fig. 4. Showing the Lamp Disconnected from the Circuit

The advantages of this cut-out cannot be overestimated. When any individual lamp needs attention from the trimmer, it can be handled with perfect safety without resorting to the insulated stool largely used by central station employees. Accidents sustained in handling the lamps will be reduced to a minimum, and thus expenses from this source will be decreased, to say nothing of prevention of loss of human life. Furthermore, flexible conductors are not required from pole to cut-out, for when the lamp is lowered the conductors remain attached to covered binding posts on the stationary or upper section. This, of itself, is important.

The insulator is constructed with due regard to dielectric qualities, and will withstand a potential of 20,000 volts under any weather conditions. It will readily be noted that its disruptive strength is entirely adequate, and in excess of the requirements of ordinary lighting service conditions. Thus the insulation between the trimmer and the line, when the lamp is lowered, is very high. The insulators possess all the mechanical attributes of the porcelain strain insulators described at length in previous issues of the REVIEW.

In designing the pulley fittings, provision was made for the use of galvanized iron, steel, or hempen lowering cables. Hempen cable is recommended on account of the increased insulation obtained, although some central stations prefer the metallic cables.

Fig. 3 is a view of the Form K multiple automatic hanger suspending a Form 12 d.c. multiple lamp at the "on" position. This device is similar to the series cut-out shown in Figs. 1 and 2, with the exception that the insulator is considerably smaller, since the potentials which it is required to withstand are comparatively low. In addition, the short-circuiting device is left out for obvious reasons and a suspension pipe for regulating the position of the cut-out is provided. The insulators are required to withstand a potential of 1500 volts under all weather conditions, this providing ample insulation for use on d.c. constant potential, or a.c. secondary lighting mains.

Fig. 4 is a cut of the same device with the lower portion removed and the standard Form 12 d.c. General Electric multiple arc lamp suspended therefrom. Cross-arms have been eliminated from this design as it is not necessary to anchor the line wires. Suitable binding posts are provided for connection to the circuit.

The advantage of a multiple automatic hanger or contact coupling of this nature is at once apparent. It can be readily attached to any ceiling, rafter, I-beam or other object of support, at any height from the floor, and the position of the lamp regulated by means of suspension pipes of different lengths. Many an armory, gymnasium, mill or public hall would have long since used arc lamps had there been any convenient and safe way of trimming or examining them. Furthermore, the annoyance heretofore caused by trimmers with their long step-ladders in crowded interiors, both to the public and management, is a thing of the past once automatic cut-outs have been installed.

A very satisfactory absolute series cut-out of the plug type, known as the Form H, is shown in Fig. 5. While this cut-out is not provided with an automatic locking device, yet after the plug is removed the lamp is entirely disconnected from the circuit and can be handled with impunity. The construction of the cut-out is novel and the quality of insulation unsurpassed. Three metallic balls are arranged within a galvanized iron cover, and are actuated by coiled steel springs which press them together. Line connections are made to the two outside balls, and the inside or middle one short-circuits or closes the line when the plug containing the lamp connecting cables is removed. When the plug is in position the middle ball is forced upward and away from the others, contact with the lamp being made by insulated metallic surfaces on either side. The plug handle is of vitrified porcelain and so designed as to prevent any possibility of reversal of polarity.

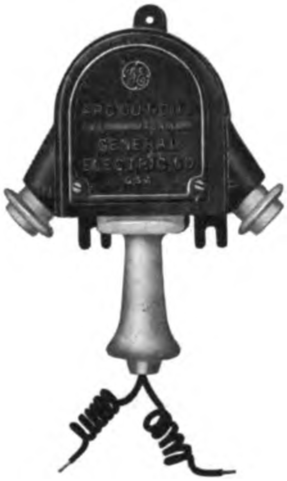


Fig. 5. Form H Plug Cut-out for Series Circuits

It is evident from the preceding description that satisfactory cut-outs for every class of service are now available.

THE JHELUM POWER INSTALLATION

Part II

By S. Orling

The dredging of the Jhelum river was started about three miles below Baramula, at which point the river bed consists of rocks and boulders, this formation extending for a stretch of about two miles. The dipper dredge is employed for the work, and obtains its power from the small substation which is located here. Above this stretch the bed is formed of clay and sand, and the two hydraulic dredges are assigned to this section, power being taken from the large substations.

The dipper dredge *Himalaya* is the first dredge in the world to be electrically operated. It handles a 4 cu. yd. dipper, and is capable of digging loose rock to a depth of 22 ft. below the water level. The electrical equipment for the main hoist machinery comprises two 150 h.p., 500 r.p.m., 2300 volt, 3 phase induction motors with definite wound rotors and collector rings, operated by a master controller and two sets of contactors of the a.c. type. These motors drive the 42 in. hoist drum through two trains of double reduction spur gears located on opposite sides of the main gear; the drum being provided with a friction clutch and a band brake, both operated by compressed air.

The dipper hoist motors are run at about 75 per cent. synchronism, so that, if the dipper sticks, the motors will automatically reduce speed and gradually increase the torque, without letting go of the load, until it reaches a maximum, at which time the motors are almost at a standstill; the torque going up about 50 per cent. At a torque slightly above this point, a clutch, which is inserted in the driving mechanism, will slip. This clutch acts as a safety valve, preventing the breakage of ropes, gears, and other parts of the mechanism. As seen from the above, the torque is kept below the slipping point, except in the case of such sudden stoppage that the fly-wheel effect of the motors produces greater torque, in which case the clutch slips and relieves the strain. The object is to obtain a characteristic very similar to that of a steam-driven dredge. When a steam engine is operating a shovel and the dipper sticks, the engine comes to a standstill; but the pressure on the shovel is maintained by the steam, and somewhat increased by the inertia of the moving parts as the engine slows down. A similar performance is obtained with a motor, somewhat at a sacrifice of efficiency, by inserting a resistance in the rotor circuit. In this case, when the dipper sticks, the motors keep pushing on the load, and the torque increases somewhat with the decrease of speed.

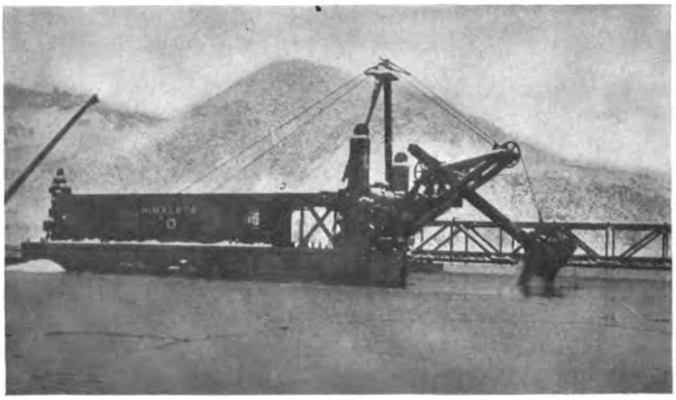


Fig. 1. The Dipper Dredge "Himalaya"

A permanent and a variable resistance are inserted in the secondary circuits, the cutting out of the latter being done by contactors. The C 49 master controller is made up of brushes moving downward over two rows of contactors. The handle, which first operates the reversing switch, sets the brushes free and allows them to fall by gravity against the action of a dashpot; the latter being adjustable. The resistance is therefore cut out in a certain time, depending upon the adjustment, the minimum time being 2 seconds. The controller circuit is 220 volts. The set of contactors for the primary circuit consists of five contactors immersed in oil, and acts as a single reversing switch for the two motors running in parallel. The secondary circuits of the motors are separate, each being connected to its own resistance. These resistance boxes are water-cooled and consist simply of iron grid rheostats immersed in water circulated by small pumps, the permanent and variable resistance for each phase being connected in series and placed in three separate compartments. The motors are enclosed and provided with a blower for forced ventilation.

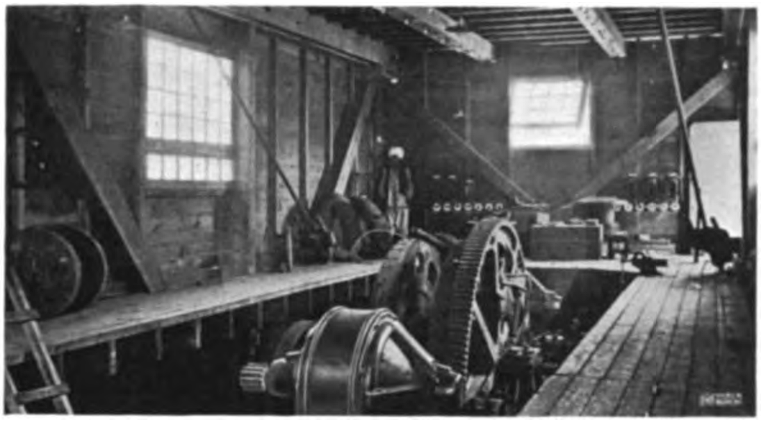


Fig. 2. Interior of the Dipper Dredge, Showing Hoist Machinery

The hoist motors also operate the spud machinery, which is connected with the hoist machinery by a chain running on sprocket wheels, a jaw clutch being used for engaging the sprockets with the hoist. When operating the spuds, the friction clutch on the hoist drum is left open. There are three spuds, one being located in each corner of the bow, and the third, the walking

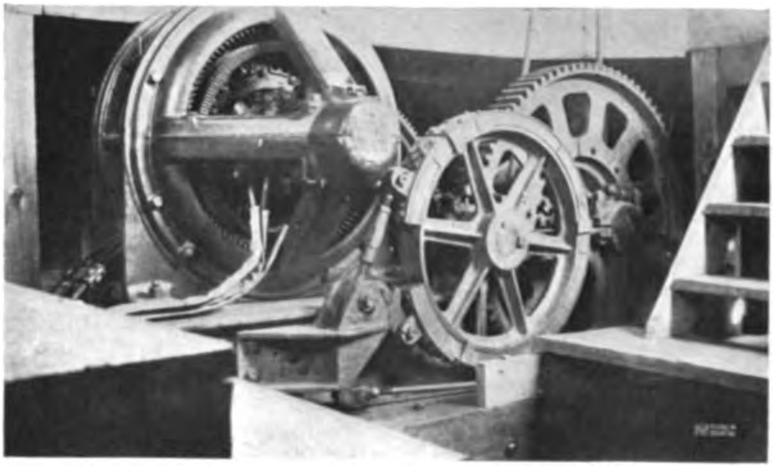


Fig. 3. Interior of Dipper Dredge, Showing the Swing Machinery

spud (by means of which the dredge is moved forward after finishing a cut), is placed in the stern.

The large triangular crane, or boom, in which the bucket handle slides, rests with one end on the lower pivoting part of the swinging table. From the upper portion of this table substantial wooden constructions support the boom, the top part of which is guyed to the A-frame by heavy 2½ in. steel ropes, the method of fastening being such as to allow the cables to swing with the crane. The A-frame is counter-guyed to the stern.

The operator of the swinging machinery has his place on a platform built on the lower portion of the swinging table, where the controller for the swing motor and the two levers for the brakes (one checking the swinging of the crane and the other the sliding of the handle) are located. The motor for this machinery is a 100 h.p., 500 r.p.m., form M induction motor, placed inside the dredge close to the hoist motors. It has a permanent resistance inserted in its rotor circuit and a variable resistance in circuit with the controller. To simplify the wiring, the latter had to be located overhead on the swinging table, close to the controller. The wiring from the controller to the switchboard and motor was done by drawing three-conductor cables into the dredge, close to the pivoting joint of the swinging table, and from there dropping them down, splicing them to separate wires, and running them on insulators in the usual manner. In addition to the work of operating the dipper, there is a load on the motor due to the rocking of the dredge when the boom swings, which, when reduced back to armature torque, amounts to about 400 ft. lb.

The dredge is provided with two capstans for hauling the scows, and for any ordinary work of the kind. A 30 h.p., form K motor drives this machinery, which is located in the hull; a 10 h.p. motor operating the air compressor and bilge pump being also located there.

The spoil dug up by the dredge is dumped on floating scows, which, when filled, are taken to the shore by a steam tug built for the purpose and anchored within reach of the travelling shore derricks.

Returning to the substations: these are securely anchored in the river by means of long wooden spuds, one at each end driven down in the soft mud. These slide through a big wooden slot in the hull, and thus make the station independent of high and low water level.

Power is transmitted to the dredge at 2300 volts pressure, through a three-conductor armored cable, 600 ft. long, carried out on rectangular wooden pontoons spaced 18 ft. apart and fastened between the spans by planks placed on swivels. Where the cable runs over these planks, it is securely boxed in to prevent it from dropping into the river. One end is lashed to a pole of the 2300 volt transmission line, and connections are made by means of special brass clamps fastened to conductors hanging down from the line to a distance of about 10 ft. from the ground. The other end of the cable is

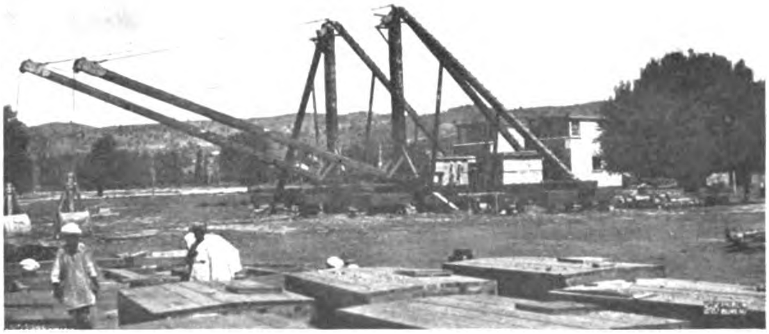


Fig. 4. Travelling Stiff-leg Derricks

connected to a triple-pole oil switch located near the walking spud on the dredge, the other side of the oil switch being connected to the switchboard in the bow end of the dredge.

There are two stiff-leg derricks, with 3-cu. yd. clam shell type buckets suspended from a boom 80 ft. long. The derricks are mounted on wheels, the boom-mast and swinging table being supported on one set of wheels and the hoisting and swinging machinery carried on another set; both sets running on the same two-rail track. The back leg, which is anchored on a timber frame, runs on four wheels on a single-rail track parallel to and about 45 ft. from the main track. There is one 100 h.p., form M motor for the hoist, and another of the same capacity for the swinging machinery. Both motors are operated by T 36 controllers. The hoist motor has a permanent resistance connected in the secondary and delivers about 1600 ft. lb. torque at rated speed. On account of the severe strain on starting, the swing motor is supplied with a permanent primary resistance, which produces a drop of approximately 300 volts. A permanent resistance is also connected in the secondary.

The moving of the derricks is accomplished by throwing in a jaw clutch on the hoist machinery, this clutch being connected with the moving gearing by a chain running on sprocket wheels.

The two hydraulic dredges *Jammu* and *Kashmir* are of the same capacity and similarly equipped, each having a 350 h.p. centrifugal pump discharging through an 18 in. pipe. The method of operating these dredges is to swing the bow of the dredges through an arc of a circle, the rotating cutter head at the bottom of the suction pipe cutting into the soil in a manner similar to that of a milling machine. The soil loosened by the cutter head is drawn up through the suction pipe by the pump. The power required to swing the dredge in one direction is considerably less than that necessary in the opposite direction (about one-half to three-quarters), as a smaller cut is taken when bringing the dredge back.

The large centrifugal pump is driven by a 10–350–300 form K induction motor direct connected to the pump shaft through a friction clutch. A sectional pulley is built round this clutch and a belt run to another pump of small size, which supplies water to the water-cooled pump shaft bearings and also to the revolving cutter head bearing, thus keeping the latter free from sand while in operation. On the same floor a 10 h.p. motor drives the priming and bilge pumps.

The bow winch machinery is placed on the deck floor, and comprises two drums 27 in. in diameter, one for each shore line, by means of which the dredge is swung in one direction or the other; and one 16 in. drum for hoisting and lowering the cutter head ladder. A 50 h.p., form M motor operates this machinery; the T 36 controller and resistance, and the levers for the clutches and brakes being placed in the operating room above.

The cutter head machinery is carried on a V-shaped frame hinged to the bow, underneath which the suction pipe is carried out to the revolving head. A 150 h.p., form M motor drives the cutter head through a shaft and gearing at a speed of 16 r.p.m.

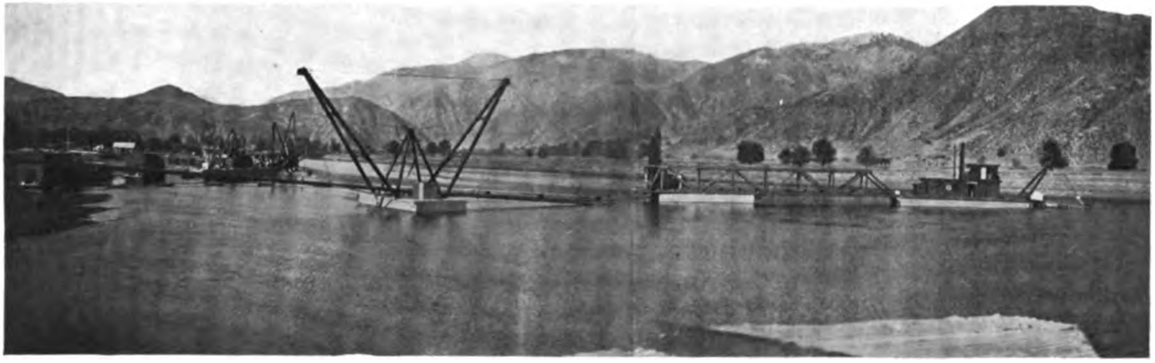


Fig. 5. Hydraulic Dredge "Jammu"

The motor pinion constitutes a friction cone clutch, and was so made to prevent the breaking of the gears in case of shocks caused by sudden stopping of the cutter head. This motor is thrown directly on the line by means of a triple-pole oil switch, a permanent resistance of 340 amps. capacity being inserted in the secondary circuit. This resistance consists of three separate iron grid type of boxes immersed in water, each box being placed in a compartment of its own and cooled with running water.

The dredge is supplied with two spuds; *viz.*, the pivoting spud, which is the center for the swinging circle of the dredge, and the walking spud, which pushes the dredge ahead after a cut is completed. When moving the dredge ahead, the walking spud is lowered and driven down in the river bed, the pivoting spud being simultaneously raised. An arm or thrust which works against the walking spud is then set in motion, the sliding base of the latter being hinged to the truss of the dredge; thus pushing the dredge ahead. The pivoting spud is then lowered and the walking spud raised, when the dredge is ready for a new cut.

There are three cable drums, two for raising and lowering the spuds, and one for the thrust, all of which are driven by a 30 h.p., form K motor. This motor is wired to start in either direction and is controlled by a triple-pole double throw oil switch located close to the motor along with the levers working the clutches and brakes.

The operating cabin has been built on the top deck, from which place the whole dredge, with the exception of the stern spud machinery, is operated. In this room are located:

(1) The switchboard, comprising four panels.

(2) Starting compensator for the 350 h.p. main pump motor.

(3) Starting compensator for the 10 h.p. priming pump motor.

(4) The T 36 controller and controller resistance for the bow winch motor.

(5) The lighting transformers.

(6) Levers for operating brakes and clutches for the bow winch machinery.

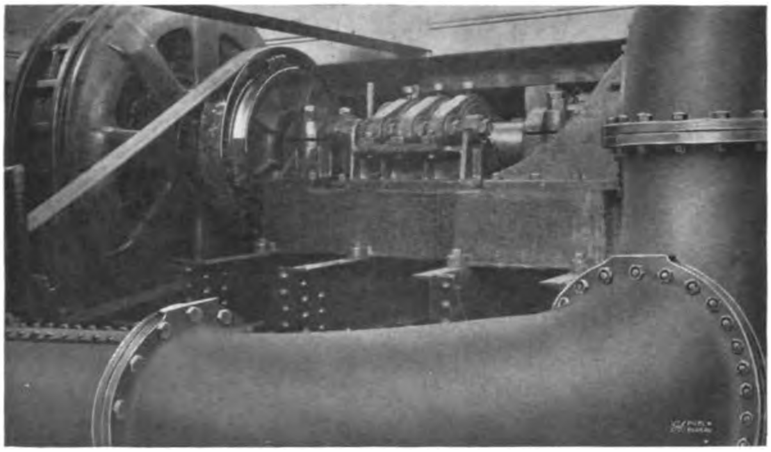


Fig. 6. Interior of the Hydraulic Dredge, Showing 350 h.p. Motor Connected to the Main Pump

The switchboard is mounted with a triple-pole oil switch for each motor and another for the lighting transformers, each switch being equipped with an overload automatic release.

The spoil dug up by the dredge is discharged on shore through an 18 in. pipe 300 ft. long, which is supported on a scow.

The production of silk is the principal industry in Kashmir, large silk factories being located in Srinagar. The driving of looms, warpers, etc., and the heating of the silk basins, has been done by means of steam;

the amount of wood consumed by boilers exceeded 1,000,000 lbs. annually. The fuel in the valley, however, is diminishing rapidly.

In connection with the power installation in Mohora and Baramula, a substation was built on the site of the silk factories. This substation is of brick, and arranged to accommodate two 60,000 volt incoming lines and two banks of transformers with a total capacity of 3000 kw. At present there are four transformers, each of 500 kw. capacity, one of which is a spare. They are arranged in one bank, with high tension and low tension windings connected in delta.

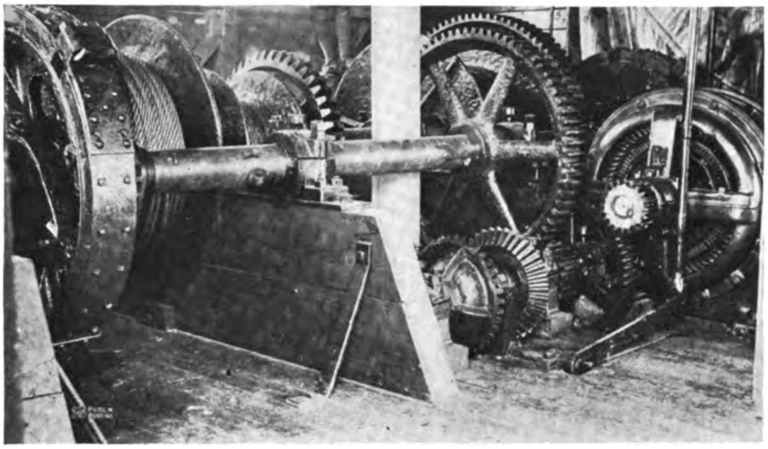


Fig. 7. Cutter Head Machinery on the Hydraulic Dredge

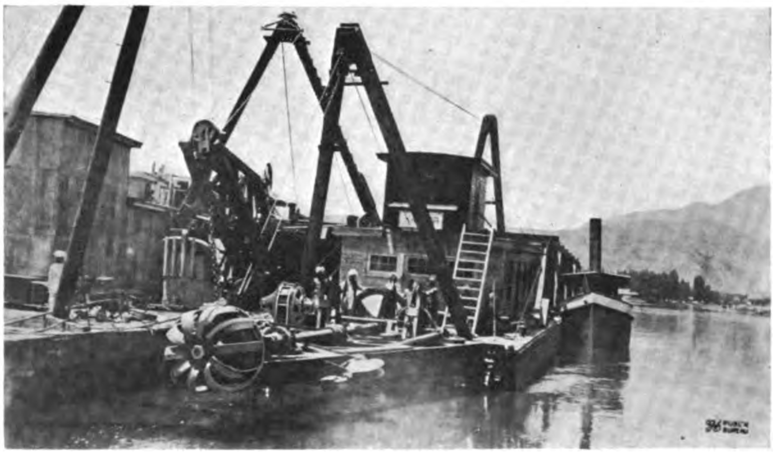


Fig. 8. Exterior of the Suction Dredge, Showing Bow Winch Machinery

The filature basins, in which the cocoons are immersed in hot water to dissolve the glue substance that holds the fine threads together, were formerly heated by steam. Three new modern filature buildings have been constructed, containing altogether 1000 basins equipped with electric heaters, 664 of which are spinning and 336 cooking basins; the spinning and cooking basins being heated by coils consuming 1000 and 800 watts, respectively. The heaters are covered with a casing of copper, the insulation between this outer casing and the resistance wire being composed of mica. The casing is, of course, water tight, in order to protect the insulation of the resistance, and also to protect the resistance wire from corrosion. For reducing the heat loss, the basins are made of galvanized iron, supported in a wooden frame with a confined air space underneath.

The power is distributed from the sub-station at a voltage of 2300 volts and is delivered to three additional transformer houses. There are three 150 kw. step-down transformers in each house, the primaries of which are connected in delta, with taps for varying voltages; and the secondaries are two coils, 115 to 230 volts, with arrangements for connecting them in either delta or Y with grounded neutral. The distribution is 3-phase. The various tap combinations give a range of from 115 volts to 225 volts.

A number of 5 h.p. variable speed induction motors are installed for driving the winding reels through counter-shafts and friction pulleys. The warpers, looms, and weaving machinery will eventually be electrically driven. The capacity of the power-house was taken sufficiently large for an eventual single-phase railway line between Rawal Pindi and Srinagar, a distance of two hundred miles, the final plans for which have not as yet been fully worked out.

The whole equipment had to be sectionalized and transported on bullock trains over the above mentioned stretch and the 9000 ft. high Murree pass. Care had to be taken when shipping the material that the cases did not exceed the limit of weight, which was four tons.

The electrical equipment of the entire installation was made by the General Electric Company; the hydraulic end was built by Abner Doble Co., San Francisco; and the dredging apparatus manufactured by the Bucyrus Co., Milwaukee

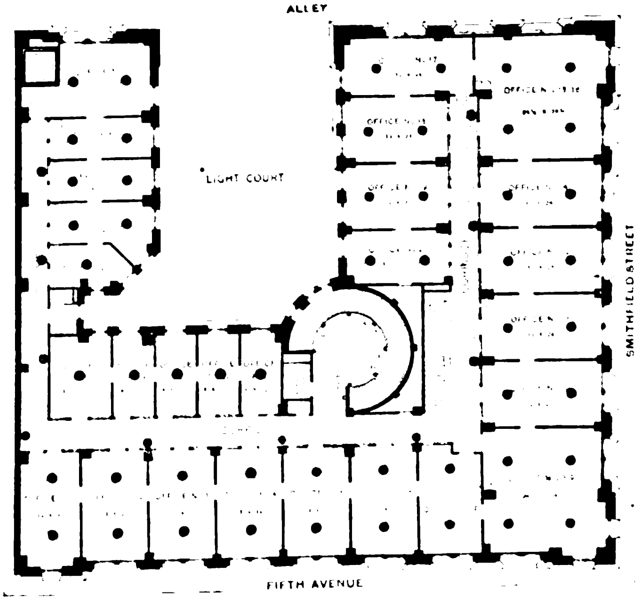
The credit of the inception and execution of this great enterprise is due to Major A. J. de Lotbiniere of the Royal Engineers, British Army, who was decorated by his Government for his distinguished services of a similar character on the well known Cauvery Power scheme in the State of Mysore.

INSTALLATION OF TUNGSTEN LAMPS IN PARK BUILDING, PITTSBURG, PA.

By L. W. Teegarten

One of the largest and most efficient installations of tungsten lamps is that of the Park Building, Pittsburg, Pa., which was recently equipped with lamps of General Electric manufacture.

This building, which is fifteen stories high and contains over 400 offices, stands at the corner of 5th Avenue and Smithfield Street, in the heart of the business district, and is one of the most prominent mercantile buildings in the city. Its thoroughly modern equipment renders it an excellent example of 20th century office buildings.



Typical Floor Plan, Park Building, Pittsburg

Until recently the illumination of the building was effected by carbon incandescent lamps located on side wall brackets. These were of the heavy coil type; and in the offices were equipped with two 16 c.p. bulbs, and in the corridors with one 32 c.p. The entire interior of the building was painted a deep sea green, with the result that the general illumination was exceedingly inadequate and of a gloomy, eye-fatiguing nature. Individual incandescent lights were necessary in almost every office, and it was often found necessary to suspend work on unusually dark days. Other problems with which the management had to contend prior to the installation of tungsten lamps were: an overloaded plant; high operating costs; and the competition of newer and more up to date buildings, which are being built yearly.

The Park Building, Pittsburg

To overcome these serious drawbacks and keep abreast of commercial progress, the management of the Park Building decided to install 1200 tungsten lamps fitted with holophane reflectors, and to repaint the entire interior of the building a light buff color. This work was carried out in accordance with the specifications and under the personal supervision of a General Electric engineer.

In changing from carbon to tungsten lamps, radical alterations were made in the wiring of the building. The side walls and ceiling of each office were cut, conduit was inserted, and leads run from the wall brackets to outlets in the ceiling. These latter were arranged on a square system as nearly as possible; the number of lamps in the three sizes of offices being as follows:

Large square rooms,	24½ ft. × 26½ ft. . .	4 lights
Long narrow offices,	13 ft. × 24 ft. . .	2 lights
Short narrow offices,	8 ft. × 21 ft. . .	1 light

The general illumination was worked out for an average intensity of light of 3 foot candles, and the best results were found to be obtained from frosted bowl 100 watt tungsten lamps fitted with clear extensive holophane reflectors; the height of the ceiling (10 ft.)

making it impracticable to use the intensive type of shade. Each unit was suspended from a neat and compact canopy placed over the ceiling outlets described above. The corridors were supplied with 40 watt clear bulb lamps placed in an inverted position; and in all outlets, such as desk lights, elevator lobby, domes, etc., 25 watt clear bulb lamps were substituted for the 16 c.p. carbons previously used.

An Office in the Park Building, Pittsburg

When all of these changes were effected, the resulting illumination was found to exceed the calculated average of 3 foot candles, owing to the excellent distribution secured and the indirect reflection afforded by the light colored walls and ceiling. The average consumption per square foot of floor surface averaged but 0.691 watts.

Apart from the consideration of the superior illumination, which was the most gratifying result of the change, a very material saving in current consumption was effected, enabling the entire electrical demands of the building to be furnished from one 125 kw. generator; whereas formerly two and sometimes three machines of a similar rating were necessary. A comparison of the old and new systems, in an approximate average consumption, is especially favorable to the tungsten lamp, as will be seen from the following:

Offices	Old System Carbon Lamps	New System Tungsten Lamps
No. floors	15	15
Brackets (or ceiling outlets) per floor	117	52
Lamps per bracket . . .	2	1
Total lamps for brackets .	3,510	780
Watts per lamp . . .	56	100
Total watts for fixtures . .	196,560	78,000
Desk lights (approx.) . .	400	200
Watts per lamp . . .	56	25
Total watts for desk lights .	22,400	5,000
Total watts for offices . .	218,960	83,000

Corridors		
Brackets per floor . . .	9	9
Watts per bracket (32 c.p. lamp)	112	40
Total watts for brackets. .	15,120	5,400
Elevator domes . . .	15	15
Total watts for elevator domes (8–16 c.p. lamps for each) .	6,720	3,000

Entire Building		
Watts for offices . . .	218,960	83,000
Watts for corridor . . .	21,840	8,400
Total watts consumption for building	240,800	91,400

FUNDAMENTAL PRINCIPLE OF RHEOSTATIC CONTROL

Part I

By A. E. Button

Industrial Control Engineering Department, General Electric Company

The simplest and most general method of controlling an electric current is by means of a resistance, which transforms a portion of the electric energy into heat and therefore nearly all controlling devices are made up of a resistance material, with means for cutting it in and out of circuit. Where the resistance is in circuit for short periods of time, a material with high thermal capacity is used, as little benefit can be expected from radiation; but if the resistance is in circuit for periods of five minutes or longer, the radiation begins to be an appreciable factor and becomes more and more so the longer the resistance is in circuit; until finally it becomes the determining factor, at which time the temperature becomes constant and the watts radiated are equal to the watts absorbed.

The unit with the greatest amount of radiating surface will dissipate the greatest number of watts under the same conditions: for this reason the General Electric Form P unit gives a very high watt rating, as its construction allows radiation of heat from both the inside and outside of the unit. The amount of ventilation also affects the number of watts that a unit will radiate for a certain temperature rise, to a much greater extent than would generally be supposed; for instance, a unit which will radiate 150 watts when suspended alone in the open air, will radiate only 50 watts when placed in an open frame with other units. As the watts on a resistance unit increase as the square of the amperes, a small increase in current over the rated capacity will cause a large increase in the temperature rise.

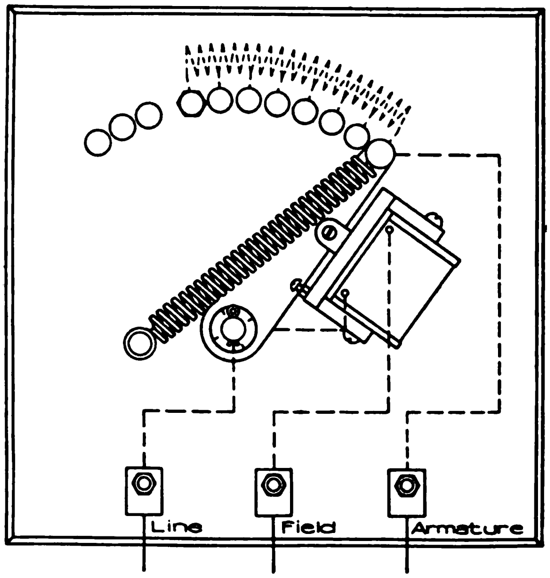


Fig. 1. Diagram of Starting Rheostat, with Coil of Retaining Magnet in Series with Motor Field

Starting Rheostats

If the motor is connected directly to the line, a large rush of current takes place, which is liable to over-heat or burn out the armature winding; or the sudden starting of the motor may injure the machinery to which the motor is connected; and for this reason, except in the case of small motors, some means is generally used to reduce the e.m.f. on the motor while it is being brought up to speed. For d.c. motors a resistance is used, and for a.c. motors either a resistance, reactance, or compensator. These devices must be designated to dissipate, during the starting period, an amount of energy equal to the capacity of the motor.

D.C. Motors

For motors requiring full load current to start, the amount of resistance necessary is equal to $\frac{E}{fLC}$; but if the motor starts with a load larger than normal, the amount of starting resistance must be reduced accordingly, and the current capacity increased. However, unless there is a specification to the contrary, it is generally assumed that the motor requires full load current at starting, and that it will be brought up to normal speed in one minute or less time. When the armature begins to revolve, it generates a counter e.m.f. which tends to cut down the current; but as soon as the switch arm is moved to the next contact, there is a sudden rise of current again. The various resistances should be so proportioned that the rise and fall of the current will take place over the same range for each contact point, assuming that the switch arm remains long enough on each point for the armature to run its full speed for that resistance. To fulfill this condition the resistance must be in a descending geometrical progression.

Connections. There are two methods used in the construction of rheostats as regards the retaining magnet. One is to connect the magnet in series with the motor field, and the other is to connect it across the line in series with a high resistance unit. The advantage of the first method is that if the motor field should in any way become open circuited, the arm of the rheostat would return to the "off" position, thus opening the armature circuit; also, in conduit work only three leads instead of four are required to be brought to the rheostat. On the other hand, the magnet must be designed for the average field current, which varies greatly for different motors of the same horse-power rating. With some motors the magnet will fail to hold the arm firmly in the running position, while with others the retaining magnet will become overheated. The advantage of the second method is that the retaining magnet is independent of the field current, and also that the same rheostat can be used with either shunt, compound or series motors.

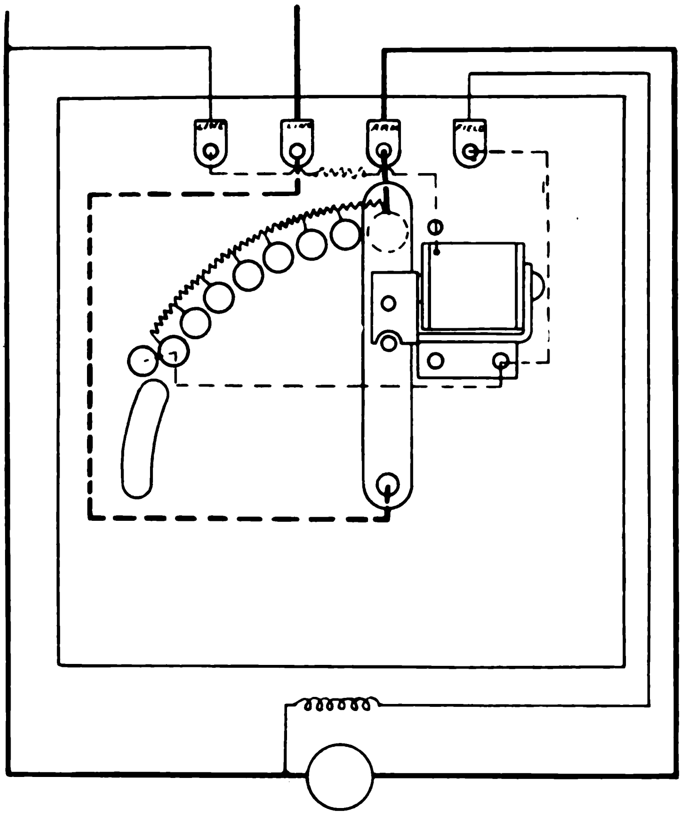


Fig. 2. Diagram of Starting Rheostat, with Coil of Retaining Magnet connected across Line

A.C. Motors

Squirrel Cage Type. For motors of this type, which require less than full voltage to start, either a resistance or a compensator can be used. For small motors a resistance has the advantage of being cheaper than a compensator, and as there are several steps of starting resistance, the motor is always brought up to speed smoothly, independent of the load on the motor; whereas a compensator having only one tap is set to start the motor with average load. If the motor is only partly loaded, too large a current will flow to give smooth acceleration, or if it is overloaded it will not start until connected directly to the line. For large motors which generally start with the same load, the compensator is more satisfactory, and is no more expensive than the resistance starter.

Resistance Type. As the squirrel cage type of motor requires a large current at starting, the rheostat must be designed accordingly, and enough resistance used to limit the current to 2.5 full load current. Should the motor require more than this current to start, the rheostat arm is moved forward, cutting out sections of resistance until the motor begins to accelerate; after which the remaining steps of resistance are gradually cut out of circuit. For two-phase motors the resistance in ohms in *each phase* is equal to $\frac{E}{2.5\times fLC}$, and for three-phase motors $\frac{E}{2.5\times fLC\times 1.73}$. If a resistance is used in only two of the three phases, the amount of resistance in each phase will be equal to $\frac{E}{2.5\times fLC\times 1.73}\times 1.5$. A resistance in each of the phases of a three-phase motor will give better starting torque than if inserted in only two of the phases.

Compensator Type. The standard starting compensators for motors of 15 h.p. or less, are provided with taps to give 40, 60 and 80 per cent. of line voltage, with a corresponding line current equal to 16, 36 and 65 per cent. of the current that would be taken by the motor if no compensator was used. For motors larger than 15 h.p., the compensator taps will give 40, 58, 70 and 85 per cent. of line voltage, with a corresponding line current equal to 16, 34, 50 and 72 per cent. of the current that would be taken by the motor without a compensator. Only one tap of the compensator is used in starting the motor, which must be that tap which will give the required starting current of the particular motor connected to it.

The amount of starting current that a motor will receive when connected to any one of the several taps of a compensator is, for 60 cycle motors, equal to $5.5\times fLC\times$ per cent. voltage tap on compensator, and for 25 and 40 cycle motors, $7\times fLC\times$ per cent. voltage tap on compensator. For instance, a 10 h.p., 220 volt, 60 cycle motor will receive $5.5\times 27\times 0.40$, or 58 amperes, when connected to the 40 per cent. voltage tap, at the same time taking only $5.5\times 27\times 0.16$, or 23 amperes from the line.

Slip Ring Type. The starting resistance for use with the slip ring type of motor is connected to the secondary circuit, and as the secondary voltage does not bear any fixed ratio to the primary voltage, it is impossible to design a starting rheostat without knowing the voltage of the motor as measured across the collector rings. After this voltage has been obtained, the ohms and amperes can be determined as follows:

$\frac{\textit{Volts across collector rings}}{1.73}$ = secondary voltage per phase.

$\frac{746\times \textit{horse power}}{3}$ = watts per phase for a three-phase motor.

$\frac{746\times \textit{horse power}}{2}$ = watts per phase for a two-phase motor.

$\frac{\textit{Watts per phase}}{\textit{Sec. voltage per phase}}$ = secondary amperes per phase.

$\frac{\textit{Secondary voltage per phase}}{\textit{Secondary amperes per phase}}$ = resistance per phase.

(To be Continued)

THE KNY-SCHEERER COMPANY

By F. J. Chisholm

The Kny-Scheerer Company of New York City, manufacturers and dealers in physicians', hospital, and medical school supplies, was originally organized to take up the American sales end of an European company of the same name. With the development of the business, show-rooms were added for the display of goods and a warehouse was established for the carrying of stock. Later, a small shop for the repair and manufacture of certain parts of the equipment sold by them was also added. In time the Company obtained the position of the largest concern of its kind in the United States, if not in the world.

With the increase of business, a larger and larger proportion of the product was made in America. As in most cases of business development, additional facilities came oftener as patches than otherwise. The year 1906 found the Company considering a reorganization of its business to enable all departments to better work together, and to arrange for the systematic extensions of facilities in place of past methods. The decision was hastened by the famous Parker Building fire at 4th Avenue and 29th Street, in the latter part of 1907, which resulted in the partial destruction of some of the Company's business offices and show-rooms

The Company was fortunate enough to get a location within three blocks of the big new Pennsylvania Railroad station, which is now under construction. The location of the site is especially favorable, due to the desire of the City to convert the blocks between 27th and 28th streets into a public park. This insured better light, because of the absence of buildings on the broadside of the building.

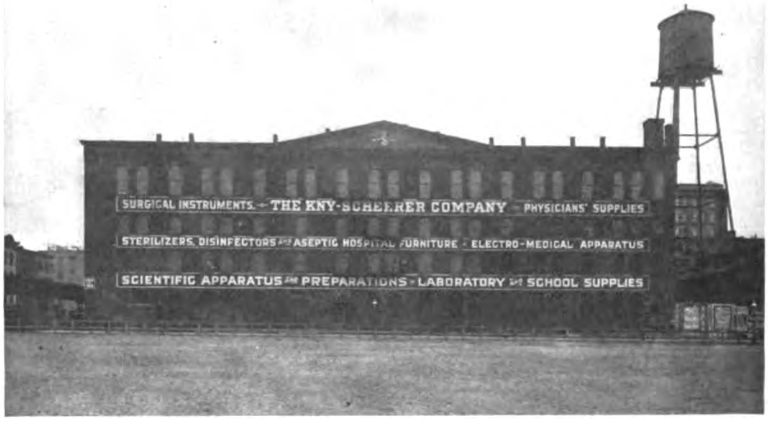

SURGICAL INSTRUMENTS — THE KNY-SCHEERER COMPANY — PHYSICIANS' SUPPLIES
STERILIZERS, DISINFECTORS AND ASEPTIC HOSPITAL FURNITURE — ELECTRO-MEDICAL APPARATUS
SCIENTIFIC APPARATUS AND PREPARATIONS — LABORATORY AND SCHOOL SUPPLIES

Fig. 1. Building of the Kny-Scheerer Company

In this building, which contains four large floors and a basement, is collected all the manufacturing and sales departments which were formerly scattered. The top floor, Fig. 2, is a show room, with an annex for the offices; the other floors with basement being devoted to shops, shipping department and warerooms.

The power question was settled, after a consideration of the various systems commonly used, by the selection of alternating current motors, fed from the two-phase 60 cycle mains of the United Electric Light and Power Company. This latter service was divided into a 110 volt system for lighting, and a 220 volt system for power work.

The shops of the Kny-Scheerer Company are divided into six departments, as follows:

Sheet metal and construction department.
Polishing and buffing department.
General machine shop and coppersmith department.
Enameling and finishing department.
Electrical apparatus department.
Surgical and instrument repair department.

The sheet metal department makes operating tables, examining tables, invalid comfort articles, and many strange devices for hospitals, sanatoria and surgeons. Sheet metal (mostly steel or iron), pipe, angle iron and bars enter into their construction. The machine tools consist of lathes, drawing benches, drills, reamers, saws, tappers and riveters. The drills, lathes and reamers are in practically constant service, while the saws, tappers and the like are used at intervals. As it was desirable to keep down first cost within a reasonable figure, the group drive was selected with the constantly operated tools in one group and the less frequently used machines in another. Two 3 h.p. motors served to take care of this department. The groups not in constant use might have been divided into two or more sections to prevent starting the whole shaft for one tool; but as the necessity of starting this shaft occurs not over five times per day, it was decided to waste a small amount of starting current, which, in many years, would not equal the investment required for the additional motors.

Fig. 2. Show Room of the Kny-Scheerer Co.

In the polishing and buffing room, a 10 h.p. motor was installed. The power requirements of this department vary widely, due to operators throwing a body weight against a piece of work being pushed against a wheel.

The intermittent character of the work, however, rendered this motor, with its big overload capacity, amply sufficient for the installation. The use of a squirrel caged motor in this department was especially desirable, due to the absence of commutators and slip rings, which would have been liable to damage from the grit from the wheels.

In the general machine shop, two 5 h.p. motors were installed on groups. Later, it is planned to put individual motors on two or three of the larger lathes in this department.

The surgical and electrical machine departments are on one floor, and at the time of their installation were not fully laid out; consequently a 5 h.p. motor was arranged to drive both sections. Plans are now being made to cut up this large drive. This will mean the application of a small motor to each of the hand lathes in the optical department. The electrical machine department manufactures motors, transformers, switchboards, centrigues, X-ray apparatus, electric light bath cabinets, and a large number of electrotherapeutic apparatus. The machine tools for this section are few in number, but frequently used, and are therefore well suited to group drive.

In the copper and brass departments, metal spinning and soldering form the principal work, and a 5 h.p. motor was installed for the few machines used here.

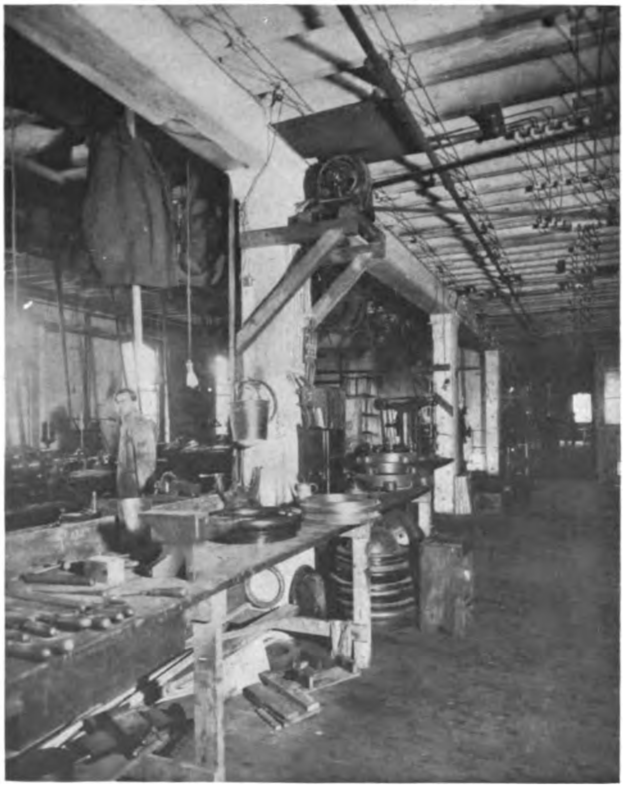


Fig. 3. Part of General Machine Shop and Coppersmith Department

The elevator proved to be the most troublesome device to equip with a motor. It had formerly been operated from a line shaft by a train of gears meshing with the pinion on the winding drum and controlled by a shift pulley mechanism. A form M, 15 h.p. motor was installed and connected directly to the main driving pulley. The motor was then connected to a reversing controller, which in turn was operated by the old rope pull device.

In addition to the manufacture and sale of X-ray apparatus, the Kny-Scheerer Company maintains a laboratory. As X-ray apparatus requires direct current, a 5 h.p. motor-generator set was installed to provide current not only sufficient for the X-ray machines, but also for the Finsen light and ultra-violet ray devices, cautery equipments, and other machines tested in this laboratory.

The total motor installation consists of 12 motors, equalling approximately 70 h.p.

The showroom is on the top floor of the building. As far as possible, the ceiling, walls, and woodwork are of white enamel finish. As the location of this room is on the top floor, the large sky-lights render the showroom very brilliant by daylight. In order to reproduce as far as possible this same effect after sun down, some 78 lights were installed on the overhead beams, which are spaced twenty feet apart for the length of the showroom. As shown in Fig. 2, these drops are now provided with white enamel metal reflectors; but it is the intention to shortly change them to those of the holophane type, with 40 watt tungsten lamps. This installation will totally avoid spot lighting. When finally equipped as intended, the illumination will equal about 3 candle feet.

In that part of the floor devoted to general offices—a sort of alcove off the main showroom—individual lights were installed, the leads being brought up through the floor and carried along the desks. In this way drop cords or cluster lighting was entirely avoided, giving free, unobstructed room over the desks.

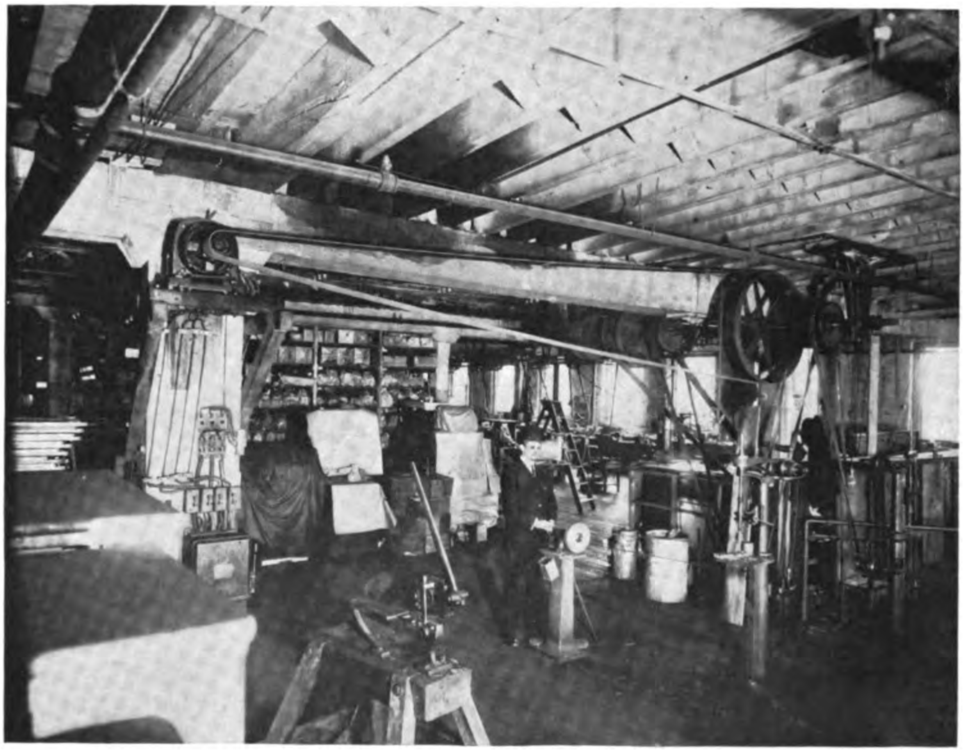


Fig. 4. In the Finishing Department

CENTRIFUGAL AIR COMPRESSORS

By Dr. Sanford A. Moss

Introduction

Centrifugal pumps have been in use for over half a century. At first, these were crudities and not looked upon seriously, but as principles of designing began to be understood, efficiencies were increased and the machine grew in favor. The success that followed the use of centrifugal pumps led to the investigation of the air compressor. The fundamental mathematical distinction between centrifugal pumps and air compressors lies in the fact that water is incompressible, while air varies its volume during the processes involved. There are also great differences in the proportions, dimensions, velocities, etc., of the two designs, and the extension of the principles of centrifugal pumps to the compression of air was therefore not a simple process. There are also practical differences between the two. Often such differences distinguish between success and failure, and a certain shape or arrangement will operate successfully with water and not with air.

The possibilities of this field attracted the attention of the General Electric Company, who were wholly independent of other experimenters, and they were very successful in getting an operative machine; even their first apparatus having a satisfactory efficiency. It is, of course, very essential to secure an operative design, on which to apply mathematical principles and formulæ.

The fan blower is in certain aspects somewhat similar to the centrifugal pump, or compressor. It is, however, usually constructed along somewhat different lines, which difference will be discussed later. There is also a great difference in degree between a single stage of a centrifugal compressor and an ordinary fan blower, and the former gives pressures many times greater than the latter. A fan blower, as used for ventilation work, gives pressures of a few tenths of a pound per square inch, while a single stage compressor as constructed by the General Electric Company gives pressures of from one to four pounds per square inch.

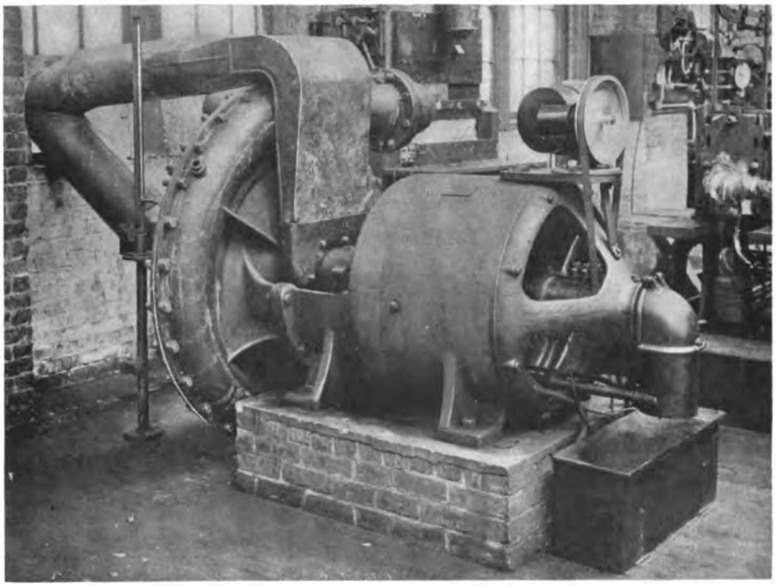


Fig. 1. Original Experimental Compressor

The centrifugal compressor, like the pump, consists of a casing containing a rotating wheel, or impeller, fitting closely but without contact. Suitable stationary passages lead the fluid to the center of the impeller, which also contains passages that lead the fluid radially outward with discharge at the periphery. Next, there are suitable stationary passages which conduct the fluid to the discharge pipe. These latter are more than mere conduits, and perform the important function of converting the impeller exit velocity into pressure. They are called diffusion passages, or discharge vanes.

Uses of Compressed Air

Air at pressures above the atmosphere is used for a great variety of purposes. At very low pressures, below about 0.2 lbs per sq. in., it is used for cooling and ventilation, the pressure being produced by fan blowers. At high pressures, above about 90 lbs. per sq. in., it is used for transmission of power to rock drills, pneumatic hammers, etc. Our present subject is not concerned with either of these applications.

For pressures of from 1 to 30 lbs. per sq. in., the centrifugal compressor is eminently adapted, and with these pressures we are mostly concerned. Air at such pressures is principally used for assisting combustion in various industrial processes. In order to melt iron in a foundry cupola, the iron is mixed with coke, etc.; air must be introduced to support the combustion; and a pressure, usually one pound per sq. in. or slightly under, is required to introduce it into the mass of lumps of coke, pig iron, etc. A similar process on a larger scale is the production of pig iron from ore in a blast furnace. The pressure required is about 15 lbs. per sq. in. Lead and copper smelters are similarly arranged.

In large manufacturing plants there are many small furnaces for hardening, annealing, melting, etc. These consist merely of a chamber lined with firebrick, into which a mixture of air, and gas or oil, is introduced through a suitable burner. Usually only a portion of the air for combustion is furnished under pressure, and the velocity of the burning jet entrains the remainder. In the case of oil, the velocity due to the pressure is necessary for atomization. Steam boilers using fuel oil frequently have a similar system. For such work there is usually required an air pressure of from 1.0 to 4.0 lbs. per sq. in., depending on the type of burner.

In these cases, and in many similar ones, a piping system of comparatively large diameter is employed, which leads the air from the source of supply to the various places at which it is needed. The pressure throughout the system is practically constant and equal to the compressor pressure. There are a number of outlets from the pipe line to the atmosphere, through orifices of burners, spaces between lumps of a cupola charge, etc., and the air escapes through these with a velocity depending on the pressure. The quantity or volume flowing is, of course, determined by the area of the outlets; if this area varies, the quantity,

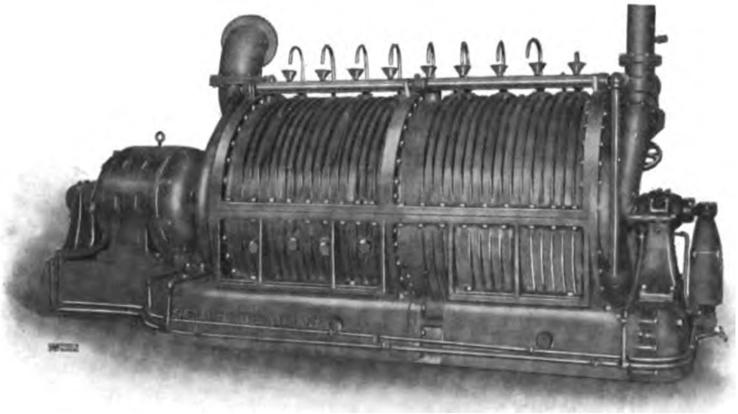


Fig. 1. General Electric Multi-Stage Compressor for 30 Pounds

and hence the load on the system, varies correspondingly. A somewhat analogous case is afforded by a constant potential electric distribution, where the load is furnished by outlets through various resistances to ground potential. The voltage corresponds to pressure, and the ampere load to the quantity of air in cubic feet per minute.

In some few cases, as in blast furnaces, a constant rate of combustion is required, demanding a constant quantity of air. The pressure is then only an incidental point, and must be that amount necessary to force this constant volume through the charge at any moment. Here, of course, a somewhat analogous case is offered by a series electric system with constant current.

Air Compressing Apparatus

In addition to the centrifugal compressor, air is furnished for the above purposes by the positive pressure blower and the low pressure reciprocating compressor. The positive pressure blower has a rotating chamber, the volume of which enlarges from zero to full value while in communication with the atmosphere. The chamber then closes and entraps the air, and brings it around to the discharge pipe. At the instant of communication, the air under pressure rushes back and compresses the new charge, causing a loss which is slight for low pressures, but which becomes serious for pressures above about 5 lbs. per sq. in., amounting to about 12 per cent. The volume of the chamber then decreases to zero, forcing the air into the discharge pipe.

There are two general designs of such apparatus; *viz.*, the cycloidal and the wing types. The cycloidal positive pressure blower has two gears, with two or more teeth intermeshing. The opening of the chamber is formed when the meshing ceases, and the air is carried around on the outside in the spaces between the teeth and forced out when meshing occurs again.

The other type is similar to the often invented rotary steam engine, and consists of a rotor with a number of sliding wings set eccentrically in a chamber.

Reciprocating compressors of the ordinary crank and piston type are also often used for pressures as low as 3 pounds per sq. in. but more usually for pressures down to 10 pounds per sq. in. Formerly these had poppet valves, opening and closing automatically, as in the ordinary high pressure air compressor. The friction drop through such valves forms a large percentage of the total pressure for low pressure work. Modern machines, therefore, have mechanically operated valves which are driven by eccentrics on the crank shaft.

For any appreciable volume such reciprocating compressors must necessarily rotate at a comparatively low speed in order to give the air an opportunity to pass through the valve openings. Heavy flywheels are also necessary, and the machines are consequently very large compared with centrifugal compressors.

Both positive pressure blowers and reciprocating compressors depend upon the fit between rubbing surfaces of rotors, valves, pistons, etc., for the prevention of leakage. There are also other rubbing surfaces in the bearings, gears, guides, etc., all of which are subject to wear and must be kept well lubricated to avoid inefficiencies. Machines that are constantly renewed and adjusted give comparatively little loss, while machines that are not properly attended to easily get into such condition as to fall off 75 per cent. in efficiency.

Machines of this type are called "displacement machines," because they displace a definite volume of air from atmosphere to pipe system at each stroke or revolution. Theoretically, when the chamber is connected to atmosphere and just before communication is closed, the entire displacement is filled with free air, or atmospheric air, all of which is delivered. Actually this is not the case, the pressure at this instant is somewhat below atmosphere, due to entrance friction, and the temperature is somewhat above, due to contact with the heated parts. During compression there is leakage from the high pressure to the low pressure side, because of the impossibility of maintaining a perfect joint between rubbing parts. Hence the air actually delivered is not the "displaced volume," but a fraction of it called the "volumetric efficiency." This varies from 95 per cent. in a new compressor in first class condition, to 25 per cent. in an old worn out machine; an average value for a fair machine being 85 per cent. The "mechanical efficiency" gives the ratio of power input to the useful power actually imparted to the air, the difference being consumed in friction of the air and of the rubbing parts. The actual efficiency of the apparatus is the product of volumetric and mechanical efficiencies.

Centrifugal Compressor Characteristics

When operated at constant speed, a centrifugal compressor, as well as a centrifugal pump or fan blower, can be used at any load from zero to overload, depending upon the openings in the pipe system. That is to say, the quantity, or volume in cubic feet passing through the machine, is simply the volume discharged through the various openings arbitrarily provided, and is a function of the pipe system and not of the compressor.

The pressure of the compressor is, however, a function of the load, and depends on the particular quantity passing. The characteristic curve of the compressor at constant speed gives the pressure for a given quantity. The shape of this curve depends on the internal design, angle of blades at impeller exit, etc. In the case of the General Electric centrifugal compressors, the curve is nearly flat for a considerable range, so that within the ordinary range of working load there is constant pressure within a few per cent. For very small loads there is some variation, and for large overloads, considerable drop.

Many centrifugal pumps and fan blowers have a continuously drooping characteristic, so that the pressure drops with each increment of load, the drop being very rapid at large loads.

For the constant pressure work previously discussed, a centrifugal compressor at constant speed gives exactly the service desired. For such work, a displacement machine is not directly adapted, and there must be some form of governing mechanism which either regulates the speed to suit the load or wastes air if less than full load amount is being used.

For cases where a centrifugal compressor is desired for constant quantity instead of constant pressure, a constant volume governor is used, generally in connection with a steam turbine.

Instead of regulating the steam openings so as to hold the shaft speed constant, as is done by the ordinary speed governor, the velocity of the air entering the inlet pipe is held constant, thus giving constant volume. The control of the velocity is accomplished by means of a float in the pipe, the tendency of which to move with the current is balanced by weights. Any tendency to disturb equilibrium actuates the steam valves.

Measurement of Air Quantity

Accurate measurements of quantity are necessary in all of this work, and have engaged a great deal of attention in the development of General Electric compressors.

The fundamental process is the measurement of velocity by means of an impact tube. This is a short open-end tube, held directly up-stream in a moving jet and connected at the other end to a device for measuring pressure (Fig. 3). The turning aside of the stream just in front of the open end of the tube causes an increase of pressure which is registered by the pressure gage.

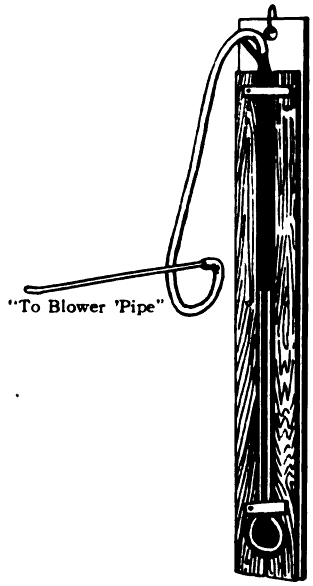


Fig 3. Measurement of Velocity by Impact Tube

When fluid flows through a nozzle there is velocity due to a given pressure difference. The theoretical velocity is, of course, a matter of definite computation from well known laws. It turns out that the stream lines in front of an impact tube form a *perfect reversed nozzle*, so that the theoretical velocity, computed for a nozzle with pressure equal to that shown by the impact tube gage, gives exactly the velocity of the jet in which the tube is placed. This law has been confirmed in numerous ways, by tank measurement by comparison with previous laws for discharge through orifices, etc. This is the well known Pitot tube, which, however, usually has two openings, one of which is identical with the impact tube just mentioned; the other being intended for measuring static pressure. However, we only determine the velocity of a jet discharging into the atmosphere: the static pressure is there known to be atmospheric.

A jet discharging into the atmosphere does not have a constant velocity throughout its section, but has lower values at the edges, with a central core of constant velocity. This fact requires that the jet be explored and a coefficient found which will give the ratio of the average velocity to the velocity in the central core. For the case of a jet over 5 inches in diameter, produced by a smooth, well rounded convergent nozzle, this velocity coefficient is close to 0.99. For a jet 1 or 2 inches in diameter, the coefficient is about 0.95.

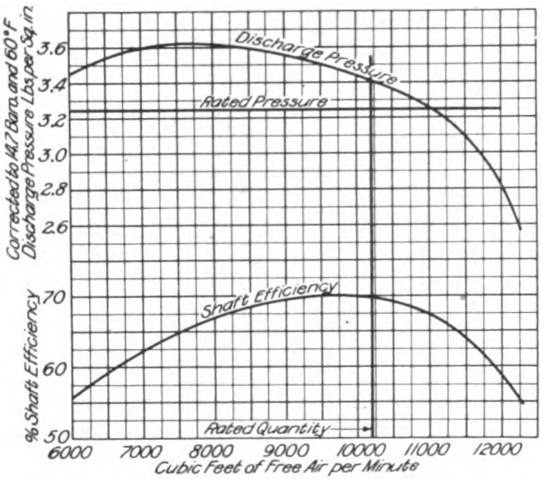


Fig. 4. Curve of Pressure and Efficiency Curve of 175 h.p. Compressor for 3 1/4 Pounds

Multi-stage Compressors

For pressures of many different values a single stage compressor is suitable. As the pressure increases, the effect of rotation losses decreases the efficiency, due to the large diameter involved. This objectionable feature can be obviated by the use of more than one stage. Various mathematical considerations concerning rotation loss, density, proportionate quantity, etc., lead to the selection of the proper number of stages for a given case, in order to secure a reasonable efficiency. Each stage is a duplicate of the single stage already discussed, with suitable passages for conducting the air from preceding stages. In this way machines for moderate quantities are constructed for pressures as high as 30 lbs., and for larger quantities for pressures of 90 pounds.

General Electric Centrifugal Compressors

The General Electric Company has developed a standard line of single stage compressors, for pressures of from 1 to 4 pounds per sq. in., in sizes of from 5 to 350 h.p., and is doing a regular commercial business. The machine with the driver forms a single unit with two bearings. The drivers are induction motors, direct current motors, or steam turbines. This line has grown directly out of the small steam turbine work, and the bearings, frames, etc., are common to the two machines. The apparatus is, of course, of the high speed type; the induction motors, when used, having two poles. A great many of these machines are in use, and they have proven very satisfactory. Some of them have been running a number of years and have required no attention or repairs whatever; nor have they been touched with a wrench since installation. Since there are no rubbing parts except the bearings, where an oil film lubrication prevents contact, there can be no wear or deterioration.

The Company is also doing multi-stage work, and among other things is constructing machines for blast furnace service, for 15 to 25 lbs. pressure and for about 22500 cu. ft. per minute, requiring about 2000 h.p.

FLAME ARC LAMPS FOR FOUNDRY AND MILL LIGHTING

By G. H. Stickney

The ordinary manufacturing plant is operated only by day, and in general, artificial illumination is required but a short time in the early morning and late afternoon of the winter days. On the other hand, many plants for manufacture of iron and steel are operated continuously, day and night, so that the question of artificial illumination becomes a most important consideration.

The presence of cranes and other powerful moving machinery makes a general illumination necessary to insure safety to the employee, as well as to expedite the process of production; and although the area to be lighted is frequently quite large, the cost of lighting is insignificant compared with the value of the machinery and the product involved, or with the loss entailed by any interruption in the proper train of manufacture. Reliability and effectiveness are then the first demands on the system of illumination.

The areas to be illuminated consist principally of large high buildings and their surrounding yards. The interiors of the buildings are generally blackened with the dust inherent in this kind of work, and the dust covered surfaces, being poor reflectors, require more light than would otherwise be necessary. Moreover, the smoke often present in the air, tends to reduce the intensity by absorption.

While no very high intensity of illumination is required for mill work, the unfavorable conditions make an exacting demand on the lighting system; these peculiar requirements are being successfully met by the flaming arc lamp. The flaming arc is drawn between two carbons impregnated with certain salts, so that when burned in air a long flaming arc is formed. The color of the light, as well as the efficiency, is dependent on the composition of the electrodes, which may be varied so as to produce yellow, white or red light. With the yellow light carbons, the arc is more efficient than any other artificial lighting unit, and this efficiency is reduced about one-half when the white light carbons are used. With the present designs of lamp, the carbons are renewed after 10 or 17 hours' burning, according to the length of carbon used.

The lamps, which usually consume 10 or 12 amperes, are run two in series on 110 volt circuits, the power consumption at 12 amperes being 500 watts for the alternating current lamp, and 660 watts for the direct current lamp.

G.E Flame Arc Lamp

Owing to the rapid falling off in light which takes place with reduction in current, the lamps cannot be operated to good advantage as small capacity units.

Lamps can be made to operate equally well on either direct or alternating current, although the lamp for the two different services differ slightly in construction.

Flaming arc lamps are generally constructed so that both carbons feed down from above in the form of a "V", making contact at the bottom. A magnet produces an electrical blowing effect, which keeps the arc on the under side of the carbon tips. This accounts for the peculiar distribution of light, which is such that the maximum intensity is directly downward, while but a very small amount of light is projected upward. All of these characteristics render the lamp particularly adaptable to the lighting requirements above described.

On account of the powerful light directed downward, it is possible to light a large building or yard with a few lamps situated forty or fifty feet above the ground, so as to be out of the way of cranes and other machinery. Other lights would be much less effective at such a height, especially if reflectors were necessary in order to project the light downward, as the reflectors would soon become blackened and lose their efficiency.

Another feature of the flaming arc which recommends it for this work is the orange-yellow quality of the light, which is absorbed less by smoke and dust in the air than any other colors, except red. This phenomenon of color absorption is illustrated in looking at the sun through a cloud of smoke or vapor, when it always appears either yellow or red, showing that these colors are penetrating the cloud while the others are absorbed.

Practically the only limitation of the flaming arc for the class of lighting here treated is the frequent trimming required. But this is off-set by the small number of units that are necessary compared to other systems. Furthermore, any lamp that could be employed should have its glassware wiped off frequently when exposed to considerable dust and smoke, and the additional time and labor required to insert carbons is negligible. When hung above a traveling crane, it is often the practice to trim lamps from the crane. In lighting the yards, the same principles apply.

Lamps can be hung from poles, trusses, roofs, etc., in many cases being provided with a lowering tackle.

The design and construction of flame arc lamps has been greatly improved within the past two years. The imported lamps contain complicated clockwork, and while this style of construction maintains fairly steady light and gives close regulation, it is somewhat delicate, and therefore difficult and expensive to repair and maintain; especially with the high price of American labor. In this country, therefore, the tendency has been to use simpler mechanisms, and follow a practice similar to that which had been adopted for other types of arc lamps.

The first American made lamps were crude and did not regulate closely, so that they gave poorer service than their European competitors. But Yankee ingenuity and perseverance have overcome these faults, and today American made lamps are obtainable which operate as well as any; moreover, they are much simpler and are more durable in construction; more ornamental in appearance, lower in first cost, and cheaper to maintain.

These advances are resulting in the adoption of the Flame lamp more and more for industrial purposes, whereas two years ago its field was limited to that of advertising display.

BOOK REVIEW

GENERAL LECTURES ON ELECTRICAL ENGINEERING

By Dr. Charles Proteus Steinmetz

Robson & Adee **284 Pages** **Price**
Schenectady, N. Y. **$2.00 Net**

This book is a collection of seventeen lectures delivered by Dr. Steinmetz to his students in Electrical Engineering; the subjects being as follows:

General review; general distribution; light and power distribution; load factor and cost of power; long distance transmission; higher harmonics of the generator wave; high frequency oscillations and surges; generation; hunting of synchronous machines; regulation and control; lightning protection; the electric railway; electric railway motor characteristics; alternating current railway motors; electro chemistry; the incandescent lamp; arc lighting.

Following these lectures two appendixes are added dealing with light and illumination, and lightning and lightning protection.

It is obvious that within the limits of a book of this size these subjects cannot be exhaustively treated, nor has it been the intention of the author to do so. He has, however, gone directly to the core of each subject and covered the essentials without waste of words and with the remarkable lucidity of presentation for which he is noted; and this with an almost entire absence of mathematical expressions, so that anyone with the merest smattering of electrical knowledge cannot fail to understand the author's explanations and deductions. The treatment of the subject of lightning phenomena is particularly happy; while the lecture on the cost of power and the relation of load factor thereto will appeal especially to many operating engineers.

The book cannot fail to be of value to both the student and the engineer; and in addition to all who are interested in Electrical Engineering and who, though lacking the necessary knowledge of mathematics—or the necessary time—for the study of the more extended treatises, still desire to become conversant with the essentials of the more important application of the science.

While as a rule engineering books are not remarkable for their literary style, it might be wished that in a book of such general interest and value more care had been taken in regard to this matter.

TABLE VI

CHARGING CURRENT

SINGLE-PHASE

SOLID CONDUCTORS

E 1000 Volts
f 25 Cycles

Chg. Current = .1571 C.
Multiply Values by 10^{-3}

In Amperes per 1000 Feet of Line (2000 ft. of wire)

Interaxial Distance, Inches	SIZE OF WIRE																		
	0000	000	00	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
3/8				2 310	.4966	.2848	.2048	.1618	.1352	.1167	.1080	.0925	.0826	.0774	.0720	.0671	.0630	.0592	.0561
1/2	.8280	.3640	.2402	.1815	.1478	.1256	.1098	.0977	.0885	.0809	.0748	.0697	.0641	.0611	.0576	.0547	.0520	.0495	.0474
3/4	.1630	.1357	.1171	.1035	.0928	.0847	.0778	.0720	.0671	.0630	.0594	.0561	.0526	.0508	.0486	.0463	.0445	.0427	.0412
1	.1100	.0982	.0886	.0811	.0748	.0696	.0650	.0611	.0578	.0548	.0520	.0496	.0470	.0454	.0437	.0419	.0404	.0390	.0377
2	.0652	.0613	.0578	.0548	.0522	.0498	.0475	.0456	.0437	.0420	.0405	.0390	.0374	.0364	.0354	.0342	.0333	.0322	.0314
3	.0534	.0509	.0482	.0465	.0446	.0429	.0413	.0397	.0383	.0371	.0360	.0349	.0338	.0327	.0317	.0309	.0302	.0294	.0286
4	.0476	.0456	.0438	.0421	.0405	.0391	.0377	.0365	.0353	.0343	.0333	.0324	.0313	.0305	.0298	.0290	.0283	.0276	.0269
5	.0438	.0421	.0405	.0391	.0379	.0366	.0355	.0344	.0333	.0324	.0314	.0306	.0297	.0291	.0283	.0276	.0270	.0264	.0258
6	.0413	.0397	.0383	.0371	.0360	.0349	.0338	.0327	.0319	.0311	.0302	.0294	.0284	.0280	.0272	.0265	.0261	.0255	.0248
7	.0393	.0380	.0368	.0355	.0344	.0335	.0325	.0316	.0306	.0299	.0291	.0284	.0275	.0270	.0264	.0258	.0253	.0247	.0242
8	.0377	.0364	.0354	.0342	.0333	.0324	.0314	.0306	.0299	.0291	.0283	.0276	.0269	.0264	.0258	.0251	.0247	.0240	.0236
9	.0365	.0353	.0342	.0333	.0324	.0314	.0306	.0299	.0291	.0283	.0276	.0270	.0262	.0258	.0251	.0246	.0240	.0236	.0231
10	.0355	.0344	.0333	.0324	.0316	.0306	.0299	.0291	.0284	.0277	.0270	.0264	.0256	.0251	.0247	.0242	.0235	.0231	.0226
11	.0346	.0335	.0325	.0317	.0308	.0300	.0292	.0284	.0278	.0270	.0265	.0259	.0251	.0247	.0242	.0237	.0232	.0228	.0223
12	.0338	.0328	.0319	.0309	.0302	.0294	.0286	.0280	.0273	.0267	.0261	.0254	.0248	.0243	.0239	.0234	.0229	.0225	.0220
15	.0319	.0311	.0302	.0294	.0288	.0280	.0273	.0267	.0261	.0255	.0250	.0245	.0237	.0234	.0229	.0225	.0220	.0217	.0212
18	.0306	.0298	.0291	.0283	.0276	.0270	.0264	.0258	.0251	.0247	.0240	.0236	.0231	.0226	.0223	.0218	.0214	.0210	.0206
21	.0295	.0287	.0281	.0273	.0267	.0261	.0256	.0250	.0245	.0239	.0234	.0229	.0225	.0221	.0217	.0212	.0209	.0204	.0201
24	.0286	.0280	.0273	.0267	.0261	.0254	.0250	.0243	.0239	.0234	.0229	.0225	.0220	.0217	.0212	.0207	.0204	.0201	.0198
30	.0273	.0267	.0261	.0255	.0250	.0243	.0239	.0234	.0229	.0225	.0220	.0217	.0212	.0209	.0204	.0201	.0198	.0195	.0192
36	.0264	.0258	.0251	.0247	.0240	.0236	.0231	.0226	.0223	.0218	.0214	.0210	.0206	.0203	.0200	.0196	.0192	.0189	.0185
42	.0256	.0250	.0248	.0239	.0234	.0229	.0225	.0221	.0217	.0212	.0209	.0206	.0201	.0198	.0195	.0192	.0189	.0185	.0182
48	.0250	.0243	.0239	.0234	.0229	.0225	.0220	.0217	.0212	.0209	.0204	.0201	.0196	.0193	.0191	.0189	.0185	.0182	.0179
54	.0243	.0239	.0234	.0229	.0225	.0220	.0218	.0212	.0209	.0205	.0201	.0198	.0193	.0190	.0189	.0186	.0182	.0179	.0176
60	.0239	.0234	.0229	.0225	.0220	.0217	.0212	.0209	.0204	.0201	.0198	.0195	.0190	.0188	.0185	.0182	.0179	.0176	.0174
66	.0236	.0231	.0226	.0221	.0217	.0214	.0209	.0206	.0202	.0198	.0195	.0192	.0188	.0185	.0182	.0179	.0177	.0174	.0172
72	.0231	.0226	.0223	.0218	.0214	.0211	.0206	.0203	.0200	.0196	.0192	.0189	.0186	.0183	.0181	.0177	.0175	.0172	.0170
78	.0228	.0224	.0220	.0215	.0212	.0208	.0204	.0200	.0198	.0194	.0190	.0187	.0184	.0181	.0179	.0176	.0173	.0171	.0168
84	.0226	.0221	.0217	.0213	.0209	.0205	.0202	.0198	.0195	.0192	.0188	.0185	.0182	.0179	.0177	.0174	.0171	.0169	.0166
90	.0223	.0219	.0215	.0210	.0207	.0203	.0200	.0196	.0193	.0190	.0186	.0183	.0180	.0178	.0175	.0172	.0170	.0167	.0165
96	.0220	.0216	.0213	.0208	.0205	.0201	.0198	.0194	.0191	.0188	.0185	.0182	.0178	.0176	.0174	.0171	.0169	.0166	.0164
102	.0218	.0214	.0211	.0206	.0203	.0199	.0196	.0192	.0189	.0186	.0183	.0180	.0177	.0175	.0173	.0170	.0167	.0165	.0163
108	.0216	.0212	.0208	.0204	.0201	.0197	.0194	.0191	.0188	.0185	.0182	.0179	.0176	.0174	.0171	.0169	.0166	.0164	.0162
114	.0214	.0210	.0207	.0203	.0199	.0196	.0193	.0189	.0186	.0183	.0181	.0177	.0175	.0173	.0170	.0168	.0165	.0163	.0160
120	.0212	.0208	.0205	.0201	.0198	.0195	.0191	.0188	.0185	.0182	.0179	.0176	.0173	.0172	.0169	.0166	.0164	.0162	.0159
126	.0211	.0207	.0203	.0200	.0197	.0193	.0190	.0187	.0184	.0181	.0178	.0175	.0172	.0170	.0168	.0165	.0163	.0161	.0158
132	.0209	.0208	.0202	.0198	.0195	.0192	.0189	.0186	.0183	.0180	.0177	.0174	.0171	.0169	.0167	.0164	.0162	.0160	.0158
138	.0208	.0204	.0201	.0197	.0194	.0190	.0188	.0185	.0182	.0179	.0176	.0173	.0170	.0168	.0166	.0163	.0161	.0159	.0157
144	.0207	.0203	.0199	.0196	.0193	.0189	.0186	.0184	.0181	.0178	.0175	.0172	.0169	.0167	.0165	.0162	.0160	.0158	.0156
150	.0205	.0201	.0198	.0195	.0191	.0188	.0185	.0183	.0180	.0177	.0174	.0171	.0168	.0166	.0164	.0162	.0159	.0157	.0155
156	.0204	.0200	.0197	.0194	.0190	.0187	.0184	.0182	.0179	.0176	.0173	.0170	.0167	.0166	.0163	.0161	.0159	.0157	.0154
162	.0203	.0199	.0196	.0193	.0189	.0186	.0183	.0181	.0178	.0175	.0172	.0170	.0166	.0165	.0162	.0160	.0158	.0156	.0154
168	.0202	.0198	.0195	.0192	.0188	.0185	.0182	.0180	.0177	.0174	.0171	.0169	.0166	.0164	.0162	.0160	.0157	.0155	.0153
174	.0201	.0197	.0194	.0191	.0187	.0184	.0181	.0179	.0176	.0173	.0170	.0168	.0165	.0163	.0161	.0159	.0157	.0155	.0153
180	.0200	.0196	.0193	.0190	.0186	.0183	.0180	.0178	.0175	.0173	.0170	.0168	.0165	.0163	.0160	.0158	.0156	.0154	.0152

Single Phase

acteristics render the lamp particularly adaptable to the lighting requirements above described.

On account of the powerful light directed downward, it is possible to light a large building or yard with a few lamps situated forty or fifty feet above the ground, so as to be out of the way of cranes and other machinery. Other lights would be much less effective at such a height, especially if reflectors were necessary in order to project the light downward, as the reflectors would soon become blackened and lose their efficiency.

Another feature of the flaming arc which recommends it for this work is the orange-yellow quality of the light, which is absorbed less by smoke and dust in the air than any other colors, except red. This phenomenon of color absorption is illustrated in looking at the sun through a cloud of smoke or vapor, when it always appears either yellow or red, showing that these colors are penetrating the cloud while the others are absorbed.

Practically the only limitation of the flaming arc for the class of lighting here treated is the frequent trimming required. But this is off-set by the small number of units that are necessary compared to other systems. Furthermore, any lamp that could be employed should have its glassware wiped off frequently when exposed to considerable dust and smoke, and the additional time and labor required to insert carbons is negligible. When hung above a traveling crane, it is often the practice to trim lamps from the crane. In lighting the yards, the same principles apply.

Lamps can be hung from poles, trusses, roofs, etc., in many cases being provided with a lowering tackle.

The design and construction of flame arc lamps has been greatly improved within the past two years. The imported lamps contain complicated clockwork, and while this style of construction maintains fairly steady light and gives close regulation, it is somewhat delicate, and therefore difficult and expensive to repair and maintain; especially with the high price of American labor. In this country therefore, the tendency has been to use simpler mechanisms, and follow a practice similar to that which had been adopted for other types of arc lamps.

The first American made lamps were crude and did not regulate closely, so that they gave poorer service than their European competitors. But Yankee ingenuity and perseverance have overcome these faults, and today American made lamps are obtainable which operate as well as any; moreover, they are much simpler and are more durable in construction; more ornamental in appearance, lower in first cost, and cheaper to maintain.

These advances are resulting in the adoption of the Flame lamp more and more for industrial purposes, whereas two years ago its field was limited to that of advertising display.

BOOK REVIEW

GENERAL LECTURES ON ELECTRICAL ENGINEERING

By Dr. Charles Proteus Steinmetz

Robson & Adee **284 Pages** **Price**
Schenectady, N. Y. **$2.00 Net**

This book is a collection of seventeen lectures delivered by Dr. Steinmetz to his students in Electrical Engineering; the subjects being as follows:

General review; general distribution; light and power distribution; load factor and cost of power; long distance transmission; higher harmonics of the generator wave; high frequency oscillations and surges; generation; hunting of synchronous machines; regulation and control; lightning protection; the electric railway; electric railway motor characteristics; alternating current railway motors; electro chemistry; the incandescent lamp; arc lighting.

Following these lectures two appendixes are added dealing with light and illumination, and lightning and lightning protection.

It is obvious that within the limits of a book of this size these subjects cannot be exhaustively treated, nor has it been the intention of the author to do so. He has, however, gone directly to the core of each subject and covered the essentials without waste of words and with the remarkable lucidity of presentation for which he is noted; and this with an almost entire absence of mathematical expressions, so that anyone with the merest smattering of electrical knowledge cannot fail to understand the author's explanations and deductions. The treatment of the subject of lightning phenomena is particularly happy; while the lecture on the cost of power and the relation of load factor thereto will appeal especially to many operating engineers.

The book cannot fail to be of value to both the student and the engineer; and in addition to all who are interested in Electrical Engineering and who, though lacking the necessary knowledge of mathematics—or the necessary time—for the study of the more extended treatises, still desire to become conversant with the essentials of the more important application of the science.

While as a rule engineering books are not remarkable for their literary style, it might be wished that in a book of such general interest and value more care had been taken in regard to this matter.

TABLE VIII

CHARGING CURRENT

SINGLE-PHASE

SOLID CONDUCTORS

Chg. Current .6283 C.
Multiply Values by 10^{-3}

In Amperes per 1000 Feet of Line (2000 ft. of Wire)

E = 1000 Volts
f = 100 Cycles

Interaxial Distance, Inches	SIZE OF WIRE 0000	000	00	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
3/8				9.238	1.986	1.138	.819	.648	.541	.467	.435	.370	.331	.310	.288	.268	.252	.237	.224
1/2	3.311	1.488	.962	.727	.592	.503	.439	.391	.354	.327	.299	.279	.256	.244	.231	.219	.208	.198	.190
3/4	.652	.543	.469	.414	.371	.339	.311	.288	.265	.252	.238	.224	.211	.203	.194	.185	.178	.171	.166
1	.441	.393	.356	.324	.299	.278	.260	.245	.231	.219	.208	.199	.188	.182	.178	.168	.162	.156	.151
2	.261	.245	.231	.219	.209	.199	.190	.182	.175	.168	.162	.156	.150	.146	.141	.137	.133	.129	.126
3	.214	.204	.193	.186	.179	.172	.166	.159	.153	.148	.144	.140	.134	.131	.127	.124	.121	.118	.114
4	.190	.182	.175	.168	.162	.157	.151	.146	.141	.137	.133	.129	.125	.122	.119	.116	.113	.111	.107
5	.175	.168	.162	.157	.151	.146	.142	.138	.133	.129	.126	.123	.119	.116	.113	.111	.108	.106	.103
6	.165	.159	.153	.148	.144	.139	.135	.131	.128	.124	.121	.118	.114	.112	.109	.106	.104	.102	.0993
7	.157	.152	.147	.142	.138	.134	.130	.126	.123	.119	.116	.114	.110	.108	.106	.103	.101	.0987	.0968
8	.151	.146	.141	.137	.133	.130	.126	.123	.119	.116	.113	.111	.107	.105	.103	.101	.0987	.0962	.0943
9	.146	.141	.137	.133	.129	.126	.123	.119	.116	.113	.111	.108	.105	.103	.101	.0987	.0962	.0943	.0924
10	.142	.138	.133	.130	.126	.123	.119	.116	.114	.111	.108	.106	.103	.101	.0987	.0968	.0943	.0924	.0905
11	.138	.134	.130	.127	.123	.120	.117	.114	.111	.108	.106	.104	.101	.0987	.0968	.0949	.0930	.0911	.0892
12	.135	.131	.128	.124	.121	.118	.114	.112	.109	.107	.104	.102	.0993	.0974	.0955	.0937	.0918	.0899	.0880
15	.128	.124	.121	.118	.115	.112	.109	.107	.104	.102	.100	.0980	.0949	.0936	.0918	.0899	.0880	.0867	.0849
18	.123	.119	.116	.113	.111	.108	.106	.103	.101	.0987	.0962	.0943	.0924	.0905	.0893	.0874	.0855	.0842	.0824
21	.118	.115	.112	.109	.107	.104	.102	.1000	.0980	.0955	.0937	.0918	.0899	.0886	.0867	.0849	.0836	.0817	.0804
24	.114	.112	.109	.107	.104	.102	.1000	.0974	.0955	.0937	.0918	.0899	.0880	.0867	.0849	.0830	.0817	.0805	.0792
30	.109	.107	.104	.102	.100	.0974	.0955	.0937	.0918	.0905	.0880	.0867	.0848	.0836	.0817	.0805	.0792	.0780	.0767
36	.106	.103	.101	.0987	.0962	.0943	.0924	.0905	.0893	.0874	.0855	.0843	.0824	.0811	.0798	.0786	.0767	.0755	.0742
42	.102	.1000	.0980	.0955	.0936	.0918	.0899	.0886	.0868	.0849	.0836	.0824	.0805	.0792	.0780	.0767	.0754	.0742	.0729
48	.100	.0974	.0955	.0936	.0915	.0905	.0880	.0867	.0849	.0836	.0817	.0805	.0786	.0773	.0767	.0754	.0742	.0729	.0716
54	.0974	.0955	.0937	.0918	.0899	.0880	.0867	.0849	.0836	.0817	.0805	.0792	.0773	.0761	.0754	.0742	.0729	.0717	.0704
60	.0955	.0937	.0918	.0899	.0880	.0867	.0849	.0836	.0817	.0805	.0792	.0780	.0761	.0754	.0742	.0729	.0717	.0704	.0698
66	.0943	.0924	.0906	.0886	.0867	.0855	.0836	.0823	.0811	.0792	.0779	.0767	.0754	.0742	.0729	.0717	.0710	.0698	.0687
72	.0924	.0905	.0893	.0874	.0855	.0842	.0823	.0811	.0799	.0783	.0770	.0757	.0743	.0733	.0723	.0710	.0700	.0690	.0679
78	.0915	.0896	.0880	.0862	.0846	.0830	.0816	.0801	.0788	.0775	.0762	.0749	.0734	.0726	.0714	.0703	.0694	.0683	.0672
84	.0903	.0884	.0869	.0852	.0836	.0821	.0807	.0793	.0780	.0766	.0753	.0741	.0727	.0718	.0707	.0697	.0686	.0676	.0666
90	.0893	.0875	.0859	.0843	.0827	.0812	.0798	.0785	.0771	.0759	.0746	.0734	.0720	.0712	.0701	.0690	.0681	.0670	.0660
96	.0882	.0866	.0850	.0834	.0819	.0805	.0790	.0778	.0764	.0752	.0740	.0728	.0714	.0705	.0695	.0684	.0675	.0664	.0655
102	.0874	.0857	.0841	.0826	.0811	.0797	.0783	.0769	.0758	.0745	.0734	.0722	.0708	.0700	.0690	.0679	.0669	.0660	.0650
108	.0865	.0849	.0834	.0819	.0805	.0790	.0776	.0764	.0751	.0739	.0728	.0716	.0702	.0695	.0685	.0675	.0664	.0655	.0646
114	.0858	.0842	.0827	.0812	.0797	.0784	.0771	.0758	.0745	.0733	.0723	.0711	.0698	.0690	.0680	.0670	.0660	.0651	.0641
120	.0850	.0835	.0820	.0806	.0792	.0778	.0768	.0752	.0741	.0729	.0717	.0706	.0693	.0685	.0675	.0665	.0656	.0646	.0638
126	.0844	.0829	.0814	.0800	.0785	.0772	.0759	.0747	.0735	.0724	.0712	.0701	.0688	.0681	.0671	.0661	.0652	.0643	.0635
132	.0838	.0823	.0808	.0793	.0780	.0767	.0755	.0742	.0731	.0720	.0707	.0698	.0685	.0677	.0667	.0657	.0648	.0639	.0631
138	.0832	.0817	.0803	.0789	.0775	.0763	.0751	.0738	.0727	.0715	.0704	.0694	.0681	.0673	.0663	.0654	.0644	.0635	.0627
144	.0827	.0812	.0797	.0783	.0771	.0758	.0745	.0734	.0722	.0710	.0700	.0690	.0677	.0670	.0660	.0651	.0641	.0632	.0624
150	.0820	.0807	.0793	.0780	.0766	.0754	.0742	.0729	.0718	.0707	.0697	.0687	.0674	.0666	.0657	.0648	.0638	.0630	.0621
156	.0816	.0802	.0788	.0775	.0762	.0750	.0737	.0726	.0714	.0703	.0693	.0683	.0670	.0663	.0654	.0644	.0635	.0627	.0618
162	.0811	.0798	.0783	.0772	.0758	.0745	.0733	.0722	.0710	.0700	.0689	.0679	.0667	.0660	.0651	.0641	.0632	.0624	.0616
168	.0807	.0793	.0780	.0767	.0755	.0742	.0730	.0718	.0707	.0697	.0686	.0676	.0664	.0657	.0648	.0639	.0630	.0621	.0614
174	.0803	.0789	.0775	.0763	.0750	.0738	.0727	.0715	.0704	.0694	.0683	.0673	.0661	.0654	.0645	.0636	.0627	.0618	.0611
180	.0798	.0783	.0772	.0759	.0747	.0735	.0723	.0711	.0701	.0691	.0681	.0671	.0659	.0651	.0643	.0633	.0625	.0616	.0608

Single-Phase

TABLE VII

CHARGING CURRENT

SINGLE-PHASE

SOLID CONDUCTORS

In Amperes per 1000 Feet of Line (2000 Ft. of Wire)

Chg. Current = .377C.
Multiply Values by 10^{-2}

E = 1000 Volts
f = 60 Cycles

Interaxial Distance, Inches	SIZE OF WIRE																		
	0000	000	00	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
3/8	...	...	...	5.546	1.192	.6830	.4913	.3883	.3243	.2800	.2593	.2220	.1982	.1857	.1726	.1610	.1512	.1421	.1345
1/2	1.9870	.8725	.5770	.4357	.3550	.3016	.2634	.2344	.2122	.1940	.1794	.1673	.1537	.1466	.1383	.1312	.1247	.1187	.1138
3/4	.3915	.3257	.2811	.2483	.2228	.2031	.1866	.1726	.1610	.1512	.1425	.1346	.1262	.1217	.1165	.1112	.1067	.1025	.0988
1	.2642	.2355	.2126	.1945	.1794	.1670	.1560	.1466	.1385	.1316	.1247	.1190	.1128	.1090	.1048	.1006	.0969	.0935	.0905
2	.1564	.1470	.1387	.1316	.1252	.1195	.1138	.1093	.1048	.1006	.0973	.0935	.0897	.0875	.0848	.0822	.0800	.0773	.0754
3	.1282	.1221	.1157	.1116	.1070	.1030	.0991	.0954	.0920	.0890	.0863	.0837	.0803	.0784	.0762	.0743	.0724	.0705	.0686
4	.1142	.1093	.1052	.1010	.0972	.0938	.0905	.0875	.0848	.0822	.0800	.0776	.0750	.0731	.0716	.0698	.0678	.0664	.0645
5	.1052	.1010	.0972	.0938	.0908	.0878	.0852	.0826	.0800	.0777	.0754	.0735	.0713	.0697	.0678	.0664	.0648	.0633	.0618
6	.0992	.0954	.0920	.0890	.0863	.0837	.0811	.0784	.0765	.0742	.0724	.0705	.0682	.0671	.0652	.0637	.0626	.0610	.0596
7	.0942	.0912	.0882	.0852	.0826	.0803	.0780	.0758	.0735	.0716	.0697	.0682	.0660	.0648	.0634	.0618	.0607	.0592	.0580
8	.0905	.0875	.0848	.0822	.0800	.0776	.0754	.0735	.0716	.0698	.0678	.0664	.0645	.0633	.0618	.0603	.0592	.0577	.0566
9	.0874	.0848	.0822	.0799	.0776	.0754	.0735	.0716	.0698	.0679	.0664	.0648	.0630	.0618	.0603	.0592	.0577	.0566	.0554
10	.0852	.0826	.0800	.0776	.0758	.0735	.0717	.0698	.0682	.0664	.0648	.0633	.0614	.0603	.0592	.0580	.0566	.0554	.0543
11	.0829	.0803	.0780	.0762	.0739	.0720	.0701	.0682	.0667	.0648	.0637	.0622	.0603	.0592	.0580	.0569	.0558	.0546	.0535
12	.0810	.0788	.0765	.0743	.0724	.0705	.0686	.0671	.0656	.0641	.0626	.0611	.0596	.0584	.0573	.0562	.0550	.0539	.0528
15	.0765	.0746	.0724	.0705	.0690	.0671	.0656	.0641	.0626	.0611	.0600	.0588	.0569	.0562	.0550	.0539	.0528	.0520	.0509
18	.0735	.0716	.0697	.0678	.0664	.0648	.0633	.0618	.0604	.0592	.0577	.0566	.0554	.0543	.0536	.0524	.0513	.0505	.0494
21	.0709	.0690	.0675	.0656	.0641	.0626	.0614	.0600	.0588	.0573	.0562	.0550	.0539	.0532	.0520	.0509	.0502	.0490	.0482
24	.0686	.0671	.0656	.0641	.0626	.0610	.0600	.0584	.0573	.0562	.0550	.0539	.0528	.0520	.0509	.0498	.0490	.0483	.0475
30	.0656	.0641	.0626	.0611	.0600	.0584	.0573	.0562	.0550	.0539	.0528	.0520	.0509	.0502	.0490	.0483	.0475	.0467	.0460
36	.0633	.0618	.0603	.0592	.0577	.0566	.0554	.0543	.0535	.0524	.0512	.0505	.0494	.0486	.0479	.0471	.0460	.0452	.0445
42	.0614	.0600	.0588	.0573	.0562	.0550	.0539	.0532	.0520	.0509	.0502	.0494	.0483	.0475	.0468	.0460	.0452	.0445	.0437
48	.0600	.0584	.0573	.0562	.0550	.0539	.0528	.0520	.0509	.0502	.0490	.0483	.0471	.0464	.0460	.0452	.0445	.0437	.0430
54	.0584	.0573	.0562	.0550	.0539	.0528	.0520	.0509	.0501	.0480	.0483	.0475	.0464	.0456	.0452	.0445	.0437	.0430	.0422
60	.0573	.0562	.0550	.0539	.0528	.0520	.0509	.0502	.0490	.0483	.0475	.0467	.0456	.0452	.0445	.0437	.0430	.0422	.0418
66	.0566	.0554	.0543	.0532	.0520	.0512	.0502	.0494	.0486	.0475	.0467	.0460	.0452	.0445	.0437	.0430	.0426	.0418	.0412
72	.0554	.0543	.0535	.0524	.0513	.0505	.0494	.0486	.0479	.0470	.0462	.0454	.0445	.0440	.0433	.0426	.0420	.0413	.0407
78	.0548	.0537	.0528	.0517	.0508	.0498	.0489	.0481	.0473	.0464	.0457	.0449	.0440	.0436	.0428	.0422	.0416	.0409	.0403
84	.0542	.0530	.0521	.0511	.0502	.0493	.0484	.0475	.0467	.0459	.0452	.0444	.0436	.0431	.0424	.0418	.0412	.0405	.0399
90	.0536	.0525	.0515	.0505	.0496	.0487	.0479	.0471	.0462	.0455	.0447	.0440	.0432	.0427	.0420	.0414	.0408	.0402	.0396
96	.0529	.0519	.0510	.0500	.0492	.0482	.0474	.0466	.0458	.0451	.0443	.0436	.0428	.0423	.0416	.0410	.0404	.0399	.0393
102	.0524	.0514	.0504	.0495	.0487	.0478	.0469	.0462	.0454	.0447	.0440	.0433	.0424	.0419	.0413	.0407	.0401	.0396	.0390
108	.0518	.0510	.0500	.0491	.0483	.0474	.0466	.0458	.0450	.0443	.0436	.0430	.0421	.0416	.0410	.0404	.0398	.0393	.0387
114	.0514	.0505	.0496	.0487	.0478	.0470	.0463	.0455	.0447	.0440	.0433	.0426	.0418	.0414	.0407	.0401	.0396	.0390	.0385
120	.0510	.0500	.0492	.0483	.0475	.0467	.0459	.0451	.0444	.0437	.0430	.0423	.0415	.0411	.0405	.0399	.0394	.0387	.0383
126	.0506	.0497	.0488	.0480	.0472	.0464	.0456	.0448	.0441	.0434	.0427	.0420	.0413	.0408	.0403	.0397	.0391	.0385	.0380
132	.0502	.0493	.0484	.0476	.0468	.0460	.0453	.0445	.0438	.0432	.0424	.0418	.0411	.0406	.0400	.0394	.0389	.0383	.0378
138	.0499	.0490	.0481	.0473	.0465	.0457	.0450	.0448	.0436	.0429	.0422	.0416	.0409	.0404	.0398	.0392	.0387	.0381	.0376
144	.0496	.0487	.0478	.0470	.0462	.0455	.0447	.0440	.0433	.0426	.0420	.0414	.0406	.0402	.0396	.0390	.0385	.0379	.0374
150	.0492	.0484	.0475	.0467	.0459	.0452	.0445	.0437	.0431	.0424	.0418	.0412	.0404	.0400	.0394	.0388	.0383	.0378	.0372
156	.0489	.0481	.0473	.0464	.0457	.0450	.0443	.0435	.0428	.0422	.0416	.0410	.0402	.0398	.0392	.0386	.0381	.0376	.0371
162	.0486	.0478	.0470	.0462	.0454	.0447	.0440	.0433	.0426	.0420	.0414	.0408	.0400	.0396	.0390	.0384	.0379	.0374	.0370
168	.0484	.0476	.0468	.0460	.0452	.0445	.0435	.0431	.0424	.0418	.0412	.0406	.0398	.0394	.0388	.0382	.0378	.0372	.0368
174	.0482	.0473	.0465	.0458	.0450	.0443	.0436	.0429	.0422	.0416	.0410	.0404	.0396	.0392	.0386	.0381	.0377	.0371	.0366
180	.0479	.0471	.0463	.0455	.0448	.0441	.0434	.0427	.0420	.0414	.0408	.0402	.0395	.0390	.0385	.0380	.0375	.0370	.0365

Single-Phase

TABLE VIII

CHARGING CURRENT

SINGLE-PHASE

Chg. Current = .6283 C.
Multiply Values by 10^{-2}

In Amperes per 1000 Feet of Line (2000 ft. of Wire)

SOLID CONDUCTORS
E = 1000 Volts
f = 100 Cycles

Interaxial Distance, Inches	SIZE OF WIRE																		
	0000	000	00	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
3/8	...	...	...	9.238	1.986	1.138	.819	.648	.541	.467	.435	.370	.331	.310	.288	.268	.252	.237	.224
1/2	3.311	1.455	.962	.727	.592	.503	.439	.391	.354	.327	.299	.279	.256	.244	.231	.219	.208	.198	.190
3/4	.652	.543	.469	.414	.371	.339	.311	.288	.268	.252	.238	.224	.211	.203	.194	.185	.178	.171	.165
1	.441	.393	.355	.324	.299	.278	.260	.245	.231	.219	.208	.199	.188	.182	.175	.168	.162	.156	.151
2	.261	.245	.231	.219	.209	.199	.190	.182	.175	.168	.162	.156	.150	.146	.141	.137	.133	.129	.126
3	.214	.204	.193	.186	.179	.172	.165	.159	.153	.148	.144	.140	.134	.131	.127	.124	.121	.118	.114
4	.190	.182	.175	.168	.162	.157	.151	.146	.141	.137	.133	.129	.125	.122	.119	.116	.113	.111	.107
5	.175	.168	.162	.157	.151	.146	.142	.138	.133	.129	.126	.123	.119	.116	.113	.111	.108	.106	.103
6	.165	.159	.153	.148	.144	.139	.135	.131	.128	.124	.121	.118	.114	.112	.109	.106	.104	.102	.0993
7	.157	.152	.147	.142	.138	.134	.130	.126	.123	.119	.116	.114	.110	.108	.106	.103	.101	.0987	.0968
8	.151	.146	.141	.137	.133	.130	.126	.123	.119	.116	.113	.111	.107	.106	.103	.101	.0987	.0962	.0943
9	.146	.141	.137	.133	.129	.126	.123	.119	.116	.113	.111	.108	.105	.103	.101	.0987	.0962	.0943	.0924
10	.142	.138	.133	.130	.126	.123	.119	.116	.114	.111	.108	.106	.103	.101	.0987	.0968	.0943	.0924	.0905
11	.138	.134	.130	.127	.123	.120	.117	.114	.111	.108	.106	.104	.101	.0987	.0968	.0949	.0930	.0911	.0892
12	.135	.131	.128	.124	.121	.118	.114	.112	.109	.107	.104	.102	.0993	.0974	.0955	.0937	.0918	.0899	.0880
15	.128	.124	.121	.118	.115	.112	.109	.107	.104	.102	.100	.0980	.0949	.0936	.0918	.0899	.0880	.0867	.0849
18	.123	.119	.116	.113	.111	.108	.106	.103	.101	.0987	.0962	.0943	.0924	.0905	.0893	.0874	.0855	.0842	.0824
21	.118	.115	.112	.109	.107	.104	.102	.1000	.0980	.0955	.0937	.0918	.0899	.0886	.0867	.0849	.0836	.0817	.0804
24	.114	.112	.109	.107	.104	.102	.1000	.0974	.0955	.0937	.0918	.0899	.0880	.0867	.0849	.0880	.0817	.0805	.0792
30	.109	.107	.104	.102	.100	.0974	.0955	.0937	.0918	.0905	.0880	.0867	.0848	.0836	.0817	.0805	.0792	.0780	.0767
36	.106	.103	.101	.0987	.0962	.0943	.0924	.0905	.0893	.0874	.0855	.0843	.0824	.0811	.0798	.0786	.0767	.0755	.0742
42	.102	.1000	.0980	.0955	.0936	.0918	.0899	.0836	.0868	.0849	.0836	.0824	.0805	.0792	.0780	.0767	.0754	.0742	.0729
48	.100	.0974	.0955	.0936	.0918	.0905	.0880	.0867	.0849	.0836	.0817	.0805	.0786	.0773	.0767	.0754	.0742	.0729	.0716
54	.0974	.0955	.0937	.0918	.0899	.0880	.0867	.0849	.0836	.0817	.0805	.0792	.0773	.0761	.0754	.0742	.0729	.0717	.0704
60	.0955	.0937	.0918	.0899	.0880	.0867	.0849	.0836	.0817	.0805	.0792	.0780	.0761	.0754	.0742	.0729	.0717	.0704	.0698
66	.0943	.0924	.0905	.0886	.0867	.0855	.0836	.0823	.0811	.0792	.0779	.0767	.0754	.0742	.0729	.0717	.0710	.0698	.0687
72	.0924	.0905	.0893	.0874	.0855	.0842	.0823	.0811	.0799	.0783	.0770	.0757	.0743	.0733	.0723	.0710	.0700	.0690	.0679
78	.0915	.0896	.0880	.0862	.0846	.0830	.0816	.0801	.0788	.0775	.0762	.0749	.0734	.0726	.0714	.0703	.0694	.0683	.0672
84	.0903	.0884	.0869	.0852	.0836	.0821	.0807	.0793	.0780	.0766	.0753	.0741	.0727	.0718	.0707	.0697	.0686	.0676	.0666
90	.0893	.0875	.0859	.0843	.0827	.0812	.0798	.0785	.0771	.0759	.0746	.0734	.0720	.0712	.0701	.0690	.0681	.0670	.0660
96	.0832	.0866	.0850	.0834	.0819	.0805	.0790	.0778	.0764	.0752	.0740	.0728	.0714	.0705	.0695	.0684	.0675	.0664	.0655
102	.0874	.0857	.0841	.0826	.0811	.0797	.0783	.0769	.0758	.0745	.0734	.0722	.0708	.0700	.0690	.0679	.0669	.0660	.0660
108	.0865	.0849	.0834	.0819	.0805	.0790	.0776	.0764	.0751	.0739	.0728	.0716	.0702	.0695	.0635	.0675	.0664	.0655	.0646
114	.0858	.0842	.0827	.0812	.0797	.0784	.0771	.0758	.0745	.0733	.0723	.0711	.0698	.0690	.0680	.0670	.0660	.0651	.0641
120	.0850	.0835	.0820	.0806	.0792	.0778	.0765	.0752	.0741	.0729	.0717	.0706	.0693	.0685	.0675	.0665	.0656	.0646	.0638
126	.0844	.0829	.0814	.0800	.0786	.0773	.0759	.0747	.0735	.0724	.0713	.0701	.0638	.0681	.0671	.0661	.0652	.0643	.0635
132	.0838	.0823	.0808	.0793	.0780	.0767	.0755	.0742	.0731	.0720	.0707	.0698	.0683	.0677	.0667	.0657	.0648	.0639	.0631
138	.0832	.0817	.0803	.0789	.0775	.0763	.0751	.0738	.0727	.0715	.0704	.0694	.0681	.0673	.0663	.0684	.0644	.0635	.0627
144	.0827	.0812	.0797	.0783	.0771	.0758	.0745	.0734	.0722	.0710	.0700	.0690	.0677	.0670	.0660	.0651	.0641	.0632	.0624
150	.0820	.0807	.0793	.0780	.0766	.0754	.0742	.0729	.0718	.0707	.0697	.0687	.0674	.0666	.0657	.0648	.0638	.0630	.0621
156	.0816	.0802	.0788	.0775	.0762	.0750	.0737	.0726	.0714	.0703	.0693	.0683	.0670	.0663	.0654	.0644	.0635	.0627	.0618
162	.0811	.0798	.0783	.0772	.0758	.0745	.0733	.0722	.0710	.0700	.0689	.0679	.0667	.0660	.0651	.0641	.0632	.0624	.0616
168	.0807	.0793	.0780	.0767	.0755	.0742	.0730	.0718	.0707	.0697	.0686	.0676	.0664	.0657	.0648	.0639	.0630	.0621	.0614
174	.0803	.0789	.0775	.0763	.0750	.0738	.0727	.0715	.0704	.0694	.0683	.0673	.0661	.0654	.0645	.0636	.0627	.0618	.0611
180	.0798	.0783	.0772	.0759	.0747	.0735	.0723	.0711	.0701	.0691	.0681	.0671	.0659	.0651	.0643	.0633	.0625	.0616	.0608

Single-Phase

INDUCTIVE REACTANCE

THREE-PHASE

Loop Formed by Two Wires of a Three-Phase Transmission Line

TABLE XI

SOLID CONDUCTORS

f = 100 Cycles per Sec.

Reactance of loop = $\sqrt{3}$ reactance for single line

Ohms per 1000 feet

Interaxial Distance, Inches	SIZE OF WIRE 0000	000	00	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Diff.
3/8	...	...	.06423	.07190	.07957	.08724	.09491	.10258	.11025	.11792	.1256	.1333	.1410	.1487	.1564	.1641	.1718	.1795	.1872	...
1/2	.06802	.07569	.08336	.09103	.09870	.10637	.11404	.12171	.12938	.13705	.1447	.1524	.1601	.1678	.1755	.1832	.1909	.1986	.2063	.0191
3/4	.09479	.10246	.11013	.11780	.12547	.13314	.14081	.14848	.15615	.16382	.1715	.1792	.1869	.1946	.2023	.2100	.2177	.2254	.2331	.0268
1	.11375	.12142	.12909	.13676	.14443	.15210	.15977	.16744	.17511	.18278	.1905	.1982	.2059	.2136	.2213	.2290	.2367	.2444	.2521	.0190
2	.15974	.16741	.17508	.18275	.19042	.19809	.20576	.21343	.22110	.22877	.2365	.2442	.2519	.2596	.2673	.2750	.2827	.2904	.2981	.0460
3	.18620	.19387	.20154	.20921	.21688	.22455	.23222	.23989	.24756	.25523	.2629	.2706	.2783	.2860	.2937	.3014	.3091	.3168	.3245	.0264
4	.20537	.21304	.22061	.22828	.23595	.24362	.25129	.25896	.26663	.27430	.2820	.2897	.2974	.3051	.3128	.3205	.3282	.3359	.3436	.0191
5	.22006	.22773	.23540	.24307	.25074	.25841	.26608	.27375	.28142	.28909	.2968	.3045	.3122	.3199	.3276	.3353	.3430	.3507	.3584	.0148
6	.23211	.23968	.24735	.25502	.26269	.27036	.27803	.28570	.29337	.30104	.3087	.3164	.3241	.3318	.3395	.3472	.3549	.3626	.3703	.0119
7	.2422	.2500	.2577	.2653	.2730	.2807	.2884	.2961	.3038	.3115	.3192	.3269	.3346	.3423	.3500	.3577	.3654	.3731	.3808	.0105
8	.2512	.2589	.2666	.2743	.2820	.2897	.2974	.3051	.3128	.3205	.3282	.3359	.3436	.3513	.3590	.3667	.3744	.3821	.3898	.0090
9	.2592	.2669	.2746	.2823	.2900	.2977	.3054	.3131	.3208	.3285	.3362	.3439	.3516	.3593	.3670	.3747	.3824	.3901	.3978	.0080
10	.2661	.2738	.2815	.2892	.2969	.3046	.3123	.3200	.3277	.3354	.3431	.3508	.3585	.3662	.3739	.3816	.3893	.3970	.4047	.0069
11	.2723	.2800	.2877	.2954	.3031	.3108	.3185	.3262	.3339	.3416	.3493	.3570	.3647	.3724	.3801	.3878	.3955	.4032	.4109	.0062
12	.2778	.2855	.2932	.3009	.3086	.3163	.3240	.3317	.3394	.3471	.3548	.3625	.3702	.3779	.3856	.3933	.4010	.4087	.4164	.0055
15	.2928	.3005	.3082	.3159	.3236	.3313	.3390	.3467	.3544	.3621	.3698	.3775	.3852	.3929	.4006	.4083	.4160	.4237	.4314	.0150
18	.3050	.3127	.3204	.3281	.3358	.3435	.3512	.3589	.3666	.3743	.3820	.3897	.3974	.4051	.4128	.4205	.4282	.4359	.4436	.0122
21	.3151	.3228	.3305	.3382	.3459	.3536	.3613	.3690	.3767	.3844	.3921	.3998	.4075	.4152	.4229	.4306	.4383	.4460	.4537	.0101
24	.3240	.3317	.3394	.3471	.3548	.3625	.3702	.3779	.3856	.3933	.4010	.4087	.4164	.4241	.4318	.4395	.4472	.4549	.4626	.0089
30	.3389	.3466	.3543	.3620	.3697	.3774	.3851	.3928	.4005	.4082	.4159	.4236	.4313	.4390	.4467	.4544	.4621	.4698	.4775	.0149
36	.3510	.3587	.3664	.3741	.3818	.3895	.3972	.4049	.4126	.4203	.4280	.4357	.4434	.4511	.4588	.4665	.4742	.4819	.4896	.0121
42	.3612	.3689	.3766	.3843	.3920	.3997	.4074	.4151	.4228	.4305	.4382	.4459	.4536	.4613	.4690	.4767	.4844	.4921	.4998	.0102
48	.3700	.3777	.3854	.3931	.4008	.4085	.4162	.4239	.4316	.4393	.4470	.4547	.4624	.4701	.4778	.4855	.4932	.5009	.5086	.0088
54	.3778	.3855	.3932	.4009	.4086	.4163	.4240	.4317	.4394	.4471	.4548	.4625	.4702	.4779	.4856	.4933	.5010	.5087	.5164	.0078
60	.3847	.3924	.4001	.4078	.4155	.4232	.4309	.4386	.4463	.4540	.4617	.4694	.4771	.4848	.4925	.5002	.5079	.5156	.5233	.0069
66	.3910	.3987	.4064	.4141	.4218	.4295	.4372	.4449	.4526	.4603	.4680	.4757	.4834	.4911	.4988	.5065	.5142	.5219	.5296	.0063
72	.3969	.4046	.4123	.4200	.4277	.4354	.4431	.4508	.4585	.4662	.4739	.4816	.4893	.4970	.5047	.5124	.5201	.5278	.5355	.0056
78	.4020	.4097	.4174	.4251	.4328	.4405	.4482	.4559	.4636	.4713	.4790	.4867	.4944	.5021	.5098	.5175	.5252	.5329	.5406	.0081
84	.4070	.4147	.4224	.4301	.4378	.4455	.4532	.4609	.4686	.4763	.4840	.4917	.4994	.5071	.5148	.5225	.5302	.5379	.5456	.0050
90	.4115	.4192	.4269	.4346	.4423	.4500	.4577	.4654	.4731	.4808	.4885	.4962	.5039	.5116	.5193	.5270	.5347	.5424	.5501	.0045
96	.4158	.4235	.4312	.4389	.4466	.4543	.4620	.4697	.4774	.4851	.4928	.5005	.5082	.5159	.5236	.5313	.5390	.5467	.5544	.0043
102	.4199	.4276	.4353	.4430	.4507	.4584	.4661	.4738	.4815	.4892	.4969	.5046	.5123	.5200	.5277	.5354	.5431	.5508	.5585	.0041
108	.4235	.4312	.4389	.4466	.4543	.4620	.4697	.4774	.4851	.4928	.5005	.5082	.5159	.5236	.5313	.5390	.5467	.5544	.5621	.0036
114	.4270	.4347	.4424	.4501	.4578	.4655	.4732	.4809	.4886	.4963	.5040	.5117	.5194	.5271	.5348	.5425	.5502	.5579	.5656	.0035
120	.4305	.4382	.4459	.4536	.4613	.4690	.4767	.4844	.4921	.4998	.5075	.5152	.5229	.5306	.5383	.5460	.5537	.5614	.5691	.0035
126	.4339	.4416	.4493	.4570	.4647	.4724	.4801	.4878	.4955	.5032	.5109	.5186	.5263	.5340	.5417	.5494	.5571	.5648	.5725	.0034
132	.4368	.4445	.4522	.4599	.4676	.4753	.4830	.4907	.4984	.5061	.5138	.5215	.5292	.5369	.5446	.5523	.5600	.5677	.5754	.0029
138	.4397	.4474	.4551	.4628	.4705	.4782	.4859	.4936	.5013	.5090	.5167	.5244	.5321	.5398	.5475	.5552	.5629	.5706	.5783	.0029
144	.4426	.4503	.4580	.4657	.4734	.4811	.4888	.4965	.5042	.5119	.5196	.5273	.5350	.5427	.5504	.5581	.5658	.5735	.5812	.0029
150	.4453	.4530	.4607	.4684	.4761	.4838	.4915	.4992	.5069	.5146	.5223	.5300	.5377	.5454	.5531	.5608	.5685	.5762	.5839	.0027
156	.4478	.4555	.4632	.4709	.4786	.4863	.4940	.5017	.5094	.5171	.5248	.5325	.5402	.5479	.5556	.5633	.5710	.5787	.5864	.0025
162	.4503	.4580	.4657	.4734	.4811	.4888	.4965	.5042	.5119	.5196	.5273	.5350	.5427	.5504	.5581	.5658	.5735	.5812	.5889	.0025
168	.4530	.4605	.4682	.4759	.4836	.4913	.4990	.5067	.5144	.5221	.5298	.5375	.5452	.5529	.5606	.5683	.5760	.5837	.5914	.0025
174	.4552	.4629	.4706	.4783	.4860	.4937	.5014	.5091	.5168	.5245	.5322	.5399	.5476	.5553	.5630	.5707	.5784	.5861	.5938	.0024
180	.4575	.4652	.4729	.4806	.4883	.4960	.5037	.5114	.5191	.5268	.5345	.5422	.5499	.5576	.5653	.5730	.5807	.5884	.5961	.0023

Three-Phase

Reactance of loop = $\sqrt{3}$ reactance
for single line

INDUCTIVE REACTANCE

THREE-PHASE

TABLE X

SOLID CONDUCTORS

Ohms per 1000 Feet

Loop Formed by Two Wires of a Three-Phase Transmission Line

f = 60 Cycles

Interaxial Distance. Inches	SIZE OF WIRE																		
	0000	000	00	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
3/8	...	...	.03859	.04319	.04779	.05239	.05699	.06159	.06619	.07079	.07539	.07999	.08459	.08919	.09379	.09839	.10299	.10759	.11219
1/2	.04080	.04540	.05000	.05460	.05920	.06380	.06840	.07300	.07760	.08220	.08680	.09140	.09600	.10060	.1052	.1098	.1144	.1190	.1236
3/4	.05688	.06148	.06608	.07068	.07528	.07988	.08448	.08908	.09368	.09828	.1029	.1075	.1121	.1167	.1213	.1259	.1305	.1351	.1397
1	.06833	.07293	.07753	.08213	.08673	.09133	.09593	.10053	.1051	.1097	.1143	.1189	.1235	.1281	.1327	.1373	.1419	.1465	.1511
2	.09585	.1005	.1051	.1097	.1143	.1189	.1235	.1281	.1327	.1373	.1419	.1465	.1511	.1557	.1603	.1649	.1695	.1741	.1787
3	.1119	.1165	.1211	.1257	.1303	.1349	.1395	.1441	.1487	.1533	.1579	.1625	.1671	.1717	.1763	.1809	.1855	.1901	.1947
4	.1234	.1280	.1326	.1372	.1418	.1464	.1510	.1556	.1602	.1648	.1694	.1740	.1786	.1832	.1878	.1924	.1970	.2016	.2062
5	.1322	.1368	.1414	.1460	.1506	.1552	.1598	.1644	.1690	.1736	.1782	.1828	.1874	.1920	.1966	.2012	.2058	.2104	.2150
6	.1394	.1440	.1486	.1532	.1578	.1624	.1670	.1716	.1762	.1808	.1854	.1900	.1946	.1992	.2038	.2084	.2130	.2176	.2222
7	.1455	.1501	.1547	.1593	.1639	.1685	.1731	.1777	.1823	.1869	.1915	.1961	.2007	.2053	.2099	.2145	.2191	.2237	.2283
8	.1508	.1554	.1600	.1646	.1692	.1738	.1784	.1830	.1876	.1922	.1968	.2014	.2060	.2106	.2152	.2198	.2244	.2290	.2336
9	.1555	.1601	.1647	.1693	.1739	.1785	.1831	.1877	.1923	.1969	.2015	.2061	.2107	.2153	.2199	.2245	.2291	.2337	.2383
10	.1597	.1643	.1689	.1735	.1781	.1827	.1873	.1919	.1965	.2011	.2057	.2103	.2149	.2195	.2241	.2287	.2333	.2379	.2425
11	.1635	.1681	.1727	.1773	.1819	.1865	.1911	.1957	.2003	.2049	.2095	.2141	.2187	.2233	.2279	.2325	.2371	.2417	.2463
12	.1669	.1715	.1761	.1807	.1853	.1899	.1945	.1991	.2037	.2083	.2129	.2175	.2221	.2267	.2313	.2359	.2405	.2451	.2497
15	.1759	.1805	.1851	.1897	.1943	.1989	.2035	.2081	.2127	.2173	.2219	.2265	.2311	.2357	.2403	.2449	.2495	.2541	.2587
18	.1830	.1876	.1922	.1968	.2014	.2060	.2106	.2152	.2198	.2244	.2290	.2336	.2382	.2428	.2474	.2520	.2566	.2612	.2658
21	.1892	.1938	.1984	.2030	.2076	.2122	.2168	.2214	.2260	.2306	.2352	.2398	.2444	.2490	.2536	.2582	.2628	.2674	.2720
24	.1945	.1991	.2037	.2083	.2129	.2175	.2221	.2267	.2313	.2359	.2405	.2451	.2497	.2543	.2589	.2635	.2681	.2727	.2773
30	.2033	.2079	.2125	.2171	.2217	.2263	.2309	.2355	.2401	.2447	.2493	.2539	.2585	.2631	.2677	.2723	.2769	.2815	.2861
36	.2105	.2151	.2197	.2243	.2289	.2335	.2381	.2427	.2473	.2519	.2565	.2611	.2657	.2703	.2749	.2795	.2841	.2887	.2933
42	.2167	.2213	.2259	.2305	.2351	.2397	.2443	.2489	.2535	.2581	.2627	.2673	.2719	.2765	.2811	.2857	.2903	.2949	.2995
48	.2219	.2265	.2311	.2357	.2403	.2449	.2495	.2541	.2587	.2633	.2679	.2725	.2771	.2817	.2863	.2909	.2955	.3001	.3047
54	.2266	.2312	.2358	.2404	.2450	.2496	.2542	.2588	.2634	.2680	.2726	.2772	.2818	.2864	.2910	.2956	.3002	.3048	.3094
60	.2308	.2354	.2400	.2446	.2492	.2538	.2584	.2630	.2676	.2722	.2768	.2814	.2860	.2906	.2952	.2998	.3044	.3090	.3136
66	.2346	.2392	.2438	.2484	.2530	.2576	.2622	.2668	.2714	.2760	.2806	.2852	.2898	.2944	.2990	.3036	.3082	.3128	.3174
72	.2381	.2427	.2473	.2519	.2565	.2611	.2657	.2703	.2749	.2795	.2841	.2887	.2933	.2979	.3025	.3071	.3117	.3163	.3209
78	.2413	.2459	.2505	.2551	.2597	.2643	.2689	.2735	.2781	.2827	.2873	.2919	.2965	.3011	.3057	.3103	.3149	.3195	.3241
84	.2442	.2488	.2534	.2580	.2626	.2672	.2718	.2764	.2810	.2856	.2902	.2948	.2994	.3040	.3086	.3132	.3178	.3224	.3270
90	.2470	.2516	.2562	.2608	.2654	.2700	.2746	.2792	.2838	.2884	.2930	.2976	.3022	.3068	.3114	.3160	.3206	.3252	.3298
96	.2495	.2541	.2587	.2633	.2679	.2725	.2771	.2817	.2863	.2909	.2955	.3001	.3047	.3093	.3139	.3185	.3231	.3277	.3323
102	.2519	.2565	.2611	.2657	.2703	.2749	.2795	.2841	.2887	.2933	.2979	.3025	.3071	.3117	.3163	.3209	.3255	.3301	.3347
108	.2542	.2588	.2634	.2680	.2726	.2772	.2818	.2864	.2910	.2956	.3002	.3048	.3094	.3140	.3186	.3232	.3278	.3324	.3370
114	.2564	.2610	.2656	.2702	.2748	.2794	.2840	.2886	.2932	.2978	.3024	.3070	.3116	.3162	.3208	.3254	.3300	.3346	.3392
120	.2584	.2630	.2676	.2722	.2768	.2814	.2860	.2906	.2952	.2998	.3044	.3090	.3136	.3182	.3228	.3274	.3320	.3366	.3412
126	.2603	.2649	.2695	.2741	.2787	.2833	.2879	.2925	.2971	.3017	.3063	.3109	.3155	.3201	.3247	.3293	.3339	.3385	.3431
132	.2621	.2667	.2713	.2759	.2805	.2851	.2397	.2943	.2989	.3035	.3081	.3127	.3173	.3219	.3265	.3311	.3357	.3403	.3449
138	.2639	.2685	.2731	.2777	.2823	.2869	.2915	.2961	.3007	.3053	.3099	.3145	.3191	.3237	.3283	.3329	.3375	.3421	.3467
144	.2656	.2702	.2748	.2794	.2840	.2886	.2932	.2978	.3024	.3070	.3116	.3162	.3208	.3254	.3300	.3346	.3392	.3438	.3484
150	.2672	.2718	.2764	.2810	.2856	.2902	.2948	.2994	.3040	.3086	.3132	.3178	.3224	.3270	.3316	.3362	.3408	.3454	.3500
156	.2688	.2734	.2780	.2826	.2872	.2918	.2964	.3010	.3056	.3102	.3148	.3194	.3240	.3286	.3332	.3378	.3424	.3470	.3516
162	.2703	.2749	.2795	.2841	.2887	.2933	.2979	.3025	.3071	.3117	.3163	.3209	.3255	.3301	.3347	.3393	.3439	.3485	.3531
168	.2717	.2763	.2809	.2855	.2991	.2947	.2993	.3039	.3085	.3131	.3177	.3223	.3269	.3315	.3361	.3407	.3453	.3499	.3545
174	.2731	.2777	.2823	.2869	.2915	.2961	.3007	.3053	.3099	.3145	.3191	.3237	.3283	.3329	.3375	.3421	.3467	.3513	.3559
180	.2744	.2790	.2836	.2882	.2928	.2974	.3020	.3066	.3112	.3158	.3204	.3250	.3296	.3342	.3388	.3434	.3480	.3526	.3572

Reactance of loop = $\sqrt{3}$ reactance
for single line

Ohms per 1000 feet

INDUCTIVE REACTANCE

THREE-PHASE

Loop Formed by Two Wires of a Three-Phase Transmission Line

TABLE XI

SOLID CONDUCTORS

f = 100 Cycles per Sec.

Interaxial Distance, Inches	SIZE OF WIRE																			
	0000	000	00	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Diff.
3/8	...	...	.06423	.07190	.07957	.08724	.09491	.10258	.11025	.11792	.1256	.1333	.1410	.1487	.1564	.1641	.1718	.1795	.1872	...
1/2	.06802	.07569	.08336	.09103	.09870	.10637	.11404	.12171	.12938	.13705	.1447	.1524	.1601	.1678	.1755	.1832	.1909	.1986	.2063	.0191
3/4	.09479	.10246	.11013	.11780	.12547	.13314	.14081	.14848	.15615	.16382	.1715	.1792	.1869	.1946	.2023	.2100	.2177	.2254	.2331	.0268
1	.11375	.12142	.12909	.13676	.14443	.15210	.15977	.16744	.17511	.18278	.1905	.1982	.2059	.2136	.2213	.2290	.2367	.2444	.2521	.0190
2	.15974	.16741	.17508	.18275	.19042	.19809	.20576	.21343	.22110	.22877	.2365	.2442	.2519	.2596	.2673	.2750	.2827	.2904	.2981	.0460
3	.18620	.19387	.20154	.20921	.21688	.22455	.23222	.23989	.24756	.25523	.2629	.2706	.2783	.2860	.2937	.3014	.3091	.3168	.3245	.0264
4	.20537	.21304	.22061	.22828	.23595	.24362	.25129	.25896	.26663	.27430	.2820	.2897	.2974	.3051	.3128	.3205	.3282	.3359	.3436	.0191
5	.22006	.22773	.23540	.24307	.25074	.25841	.26608	.27375	.28142	.28909	.2968	.3045	.3122	.3199	.3276	.3353	.3430	.3507	.3584	.0148
6	.23211	.23968	.24735	.25502	.26269	.27036	.27803	.28570	.29337	.30104	.3087	.3164	.3241	.3318	.3395	.3472	.3549	.3626	.3703	.0119
7	.2422	.2500	.2577	.2653	.2730	.2807	.2884	.2961	.3038	.3115	.3192	.3269	.3346	.3423	.3500	.3577	.3654	.3731	.3808	.0105
8	.2512	.2589	.2666	.2743	.2820	.2897	.2974	.3051	.3128	.3205	.3282	.3359	.3436	.3513	.3590	.3667	.3744	.3821	.3898	.0090
9	.2592	.2669	.2746	.2823	.2900	.2977	.3054	.3131	.3208	.3285	.3362	.3439	.3516	.3593	.3670	.3747	.3824	.3901	.3978	.0080
10	.2661	.2738	.2815	.2892	.2969	.3046	.3123	.3200	.3277	.3354	.3431	.3508	.3585	.3662	.3739	.3816	.3893	.3970	.4047	.0069
11	.2723	.2800	.2877	.2954	.3031	.3108	.3185	.3262	.3339	.3416	.3493	.3570	.3647	.3724	.3801	.3878	.3955	.4032	.4109	.0062
12	.2778	.2855	.2932	.3009	.3086	.3163	.3240	.3317	.3394	.3471	.3548	.3625	.3702	.3779	.3856	.3933	.4010	.4087	.4164	.0055
15	.2928	.3005	.3082	.3159	.3236	.3313	.3390	.3467	.3544	.3621	.3698	.3775	.3852	.3929	.4006	.4083	.4160	.4237	.4314	.0150
18	.3050	.3127	.3204	.3281	.3358	.3435	.3512	.3589	.3666	.3743	.3820	.3897	.3974	.4051	.4128	.4205	.4282	.4359	.4436	.0122
21	.3151	.3228	.3305	.3382	.3459	.3536	.3613	.3690	.3767	.3844	.3921	.3998	.4075	.4152	.4229	.4306	.4383	.4460	.4537	.0101
24	.3240	.3317	.3394	.3471	.3548	.3625	.3702	.3779	.3856	.3933	.4010	.4087	.4164	.4241	.4318	.4395	.4472	.4549	.4626	.0089
30	.3389	.3466	.3543	.3620	.3697	.3774	.3851	.3928	.4005	.4082	.4159	.4236	.4313	.4390	.4467	.4544	.4621	.4698	.4775	.0149
36	.3510	.3587	.3664	.3741	.3818	.3895	.3972	.4049	.4126	.4203	.4280	.4357	.4434	.4511	.4588	.4665	.4742	.4819	.4896	.0121
42	.3612	.3689	.3766	.3843	.3920	.3997	.4074	.4151	.4228	.4305	.4382	.4459	.4536	.4613	.4690	.4767	.4844	.4921	.4998	.0102
48	.3700	.3777	.3854	.3931	.4008	.4085	.4162	.4239	.4316	.4393	.4470	.4547	.4624	.4701	.4778	.4855	.4932	.5009	.5086	.0088
54	.3778	.3855	.3932	.4009	.4086	.4163	.4240	.4317	.4394	.4471	.4548	.4625	.4702	.4779	.4856	.4933	.5010	.5087	.5164	.0078
60	.3847	.3924	.4001	.4078	.4155	.4232	.4309	.4386	.4463	.4540	.4617	.4694	.4771	.4848	.4928	.5002	.5079	.5156	.5233	.0069
66	.3910	.3987	.4064	.4141	.4218	.4295	.4372	.4449	.4526	.4603	.4680	.4757	.4834	.4911	.4988	.5065	.5142	.5219	.5296	.0063
72	.3969	.4046	.4123	.4200	.4277	.4354	.4431	.4508	.4585	.4662	.4739	.4816	.4893	.4970	.5047	.5124	.5201	.5278	.5355	.0056
78	.4020	.4097	.4174	.4251	.4328	.4405	.4482	.4559	.4636	.4713	.4790	.4867	.4944	.5021	.5098	.5175	.5252	.5329	.5406	.0051
84	.4070	.4147	.4224	.4301	.4378	.4455	.4532	.4609	.4686	.4763	.4840	.4917	.4994	.5071	.5148	.5225	.5302	.5379	.5456	.0050
90	.4115	.4192	.4269	.4346	.4423	.4500	.4577	.4654	.4731	.4808	.4885	.4962	.5039	.5116	.5193	.5270	.5347	.5424	.5501	.0045
96	.4158	.4235	.4312	.4389	.4466	.4543	.4620	.4697	.4774	.4851	.4928	.5005	.5082	.5159	.5236	.5313	.5390	.5467	.5544	.0043
102	.4199	.4276	.4353	.4430	.4507	.4584	.4661	.4738	.4815	.4892	.4969	.5046	.5123	.5200	.5277	.5354	.5431	.5508	.5585	.0041
108	.4235	.4312	.4389	.4466	.4543	.4620	.4697	.4774	.4851	.4928	.5005	.5082	.5159	.5236	.5313	.5390	.5467	.5544	.5621	.0036
114	.4270	.4347	.4424	.4501	.4578	.4655	.4732	.4809	.4886	.4963	.5040	.5117	.5194	.5271	.5348	.5425	.5502	.5579	.5656	.0035
120	.4305	.4382	.4459	.4536	.4613	.4690	.4767	.4844	.4921	.4998	.5075	.5152	.5229	.5306	.5383	.5460	.5537	.5614	.5691	.0035
126	.4339	.4416	.4493	.4570	.4647	.4724	.4801	.4878	.4955	.5032	.5109	.5186	.5263	.5340	.5417	.5494	.5571	.5648	.5725	.0034
132	.4368	.4445	.4522	.4599	.4676	.4753	.4830	.4907	.4984	.5061	.5138	.5215	.5292	.5369	.5446	.5523	.5600	.5677	.5754	.0029
138	.4397	.4474	.4551	.4628	.4705	.4782	.4359	.4936	.5013	.5090	.5167	.5244	.5321	.5398	.5475	.5552	.5629	.5706	.5783	.0029
144	.4426	.4503	.4580	.4657	.4734	.4811	.4888	.4965	.5042	.5119	.5196	.5273	.5350	.5427	.5504	.5581	.5658	.5735	.5812	.0029
150	.4453	.4530	.4607	.4684	.4761	.4838	.4915	.4992	.5069	.5146	.5223	.5300	.5377	.5454	.5531	.5608	.5685	.5762	.5839	.0027
156	.4478	.4555	.4632	.4709	.4786	.4863	.4940	.5017	.5094	.5171	.5248	.5325	.5402	.5479	.5556	.5633	.5710	.5787	.5864	.0025
162	.4503	.4580	.4657	.4734	.4811	.4888	.4965	.5042	.5119	.5196	.5273	.5350	.5427	.5504	.5581	.5658	.5735	.5812	.5889	.0025
168	.4530	.4605	.4632	.4759	.4836	.4913	.4990	.5067	.5144	.5221	.5298	.5375	.5452	.5529	.5606	.5683	.5760	.5837	.5914	.0025
174	.4552	.4629	.4706	.4783	.4860	.4937	.5014	.5091	.5168	.5245	.5322	.5399	.5476	.5553	.5630	.5707	.5784	.5861	.5938	.0024
180	.4575	.4652	.4729	.4806	.4883	.4960	.5037	.5114	.5191	.5268	.5345	.5422	.5499	.5576	.5653	.5730	.5807	.5884	.5961	.0023

Three-Phase

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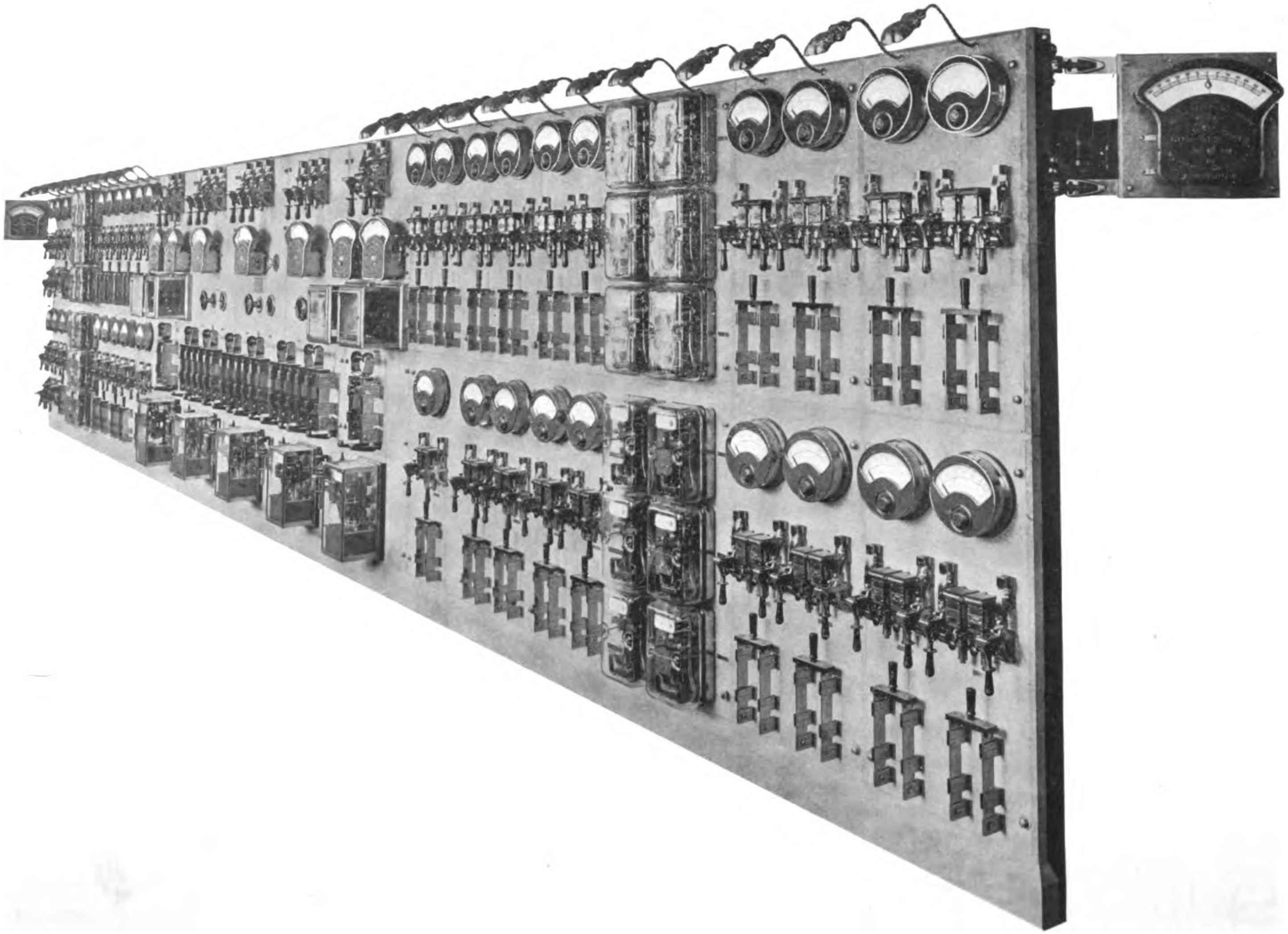


D.C. Switchboard for United States Mint, San Francisco, Cal.

(See page 412)

GENERAL ELECTRIC REVIEW

HANDICAPS TO ELECTRICAL PROGRESS IN ENGLAND

The differences between electrical engineering in this country and in England, pointed out in Mr. Conover's interesting article in this month's Review, are but one aspect of the much larger question which is involved in the commercial and industrial conditions of the two countries, due to their history, geographical position, and climate. England is an old country, rapidly becoming over-populated by a people largely of Saxon origin, one of whose chief characteristics is conservatism. This feeling has been fostered through generations by the men who have directed the policies and industries of the nation, and business and trading methods have thus been crystalized into forms which have become in some cases traditional, while at the same time the most powerful vested interests have grown up, against which newer and more up-to-date methods prevail with difficulty. As a natural result, a new industry like electrical engineering is hampered from the start.

On the other hand, in a new, large, and rapidly developing country like America, with its industries protected by tariff and with a climate which imparts a sanguine temperament to its people, no such handicaps are encountered. What wonder then, that engineering conditions are so different!

The policy of free trade in England has had the effect of increasing the competition not only of neighboring countries but also of America. The individualism of the English has only lately allowed *them* to use the best weapon with which they could combat this difficulty; namely, the standardizing of engineering products. In America standardization was long ago realized as the best means for producing apparatus quickly and cheaply. In England, on the contrary, a number of manufacturing firms came into existence at the very outset, with the sole purpose of supplying the material ordered; no co-operation was attempted, and the severity of competition was thereby increased. Partly in consequence, many engineers became consultants and were able to force their designs on manufacturing concerns, with the result that in many contracts special machinery was supplied, the character of which was largely determined by the idiosyncrasies of the engineer. Great delay in delivery and increased prices have thus been occasioned, which in many cases have more than offset the advantages of cheap labor. Improvement and advance in electrical design and development have been considerably checked by this state of affairs, as well as by the causes mentioned in the author's article.

In the very early days of the industry, company promoters held out golden promises of the possibilities of the new art, and companies were hurriedly formed and shares eagerly subscribed, for projects which would have appeared impracticable, on business if not on engineering grounds, when dispassionately considered. The failure of these schemes and the great loss of money incurred by the public, made people shy of investing further, even in sound ventures. Thus for quite a long time, no money could be raised for electrical enterprise, and progress was impossible.

Parliamentary sanction by special Act must be secured in England before any undertaking can be commenced, and in many cases the conflicting interests in the area to be served manage to delay and often to frustrate all efforts of the promoting companies to pass their bills. Municipalities are frequently jealous of private enterprise and take a dog-in-the-manger policy towards the latter. These conditions prevent the quick advancement of the industry, add heavily to the cost of undertakings, and discourage financiers from interesting themselves in commercial propositions.

Many of these conditions have been or are being ameliorated, and, considering the heavy burdens and severe handicaps under which the electrical industry in England has had to labor, there is considerable cause for congratulation that she has achieved so much. This is specially true, when it is remembered that nature affords no such opportunities for cheap power as are found in America.

CONSTANT POTENTIAL TRANSFORMERS

The constant potential transformer is of peculiar interest to the electrical engineer from the fact that it now plays an important part in nearly every branch of the electrical industry.

It is the connecting link in every transmission system, without which hydro-electric developments would have to measure their real value by the amount of business which the promoter could induce capitalists to establish in the immediate vicinity of the water power plant. Without the transformer, therefore, lighting, power and railway projects would become very limited in their scope.

For a considerable time capacities were limited to units of 25 kw. capacity and voltages of a few thousand volts: today transformers are built in capacities as high as 10,000 kw., and for voltages in excess of 100,000, with absolute certainty as to their successful commercial operation. Notwithstanding these present high limits, the engineer stands ready to manufacture transformers of even larger capacities and for voltages greatly in excess of the present commercial demands. The further development of the constant potential transformer, therefore, now awaits the demands of the transmission engineer.

The enormous capacities in which it is possible to successfully manufacture transformers today is largely due to methods which the designing engineers have evolved for subdividing portions of the transformer into sections, whereby the heat can be carried away through a proper cooling medium circulating through the various channels provided for it. The wide range of capacities and the many varieties of service in which transformers are employed, has naturally divided them into distinct types, each type being characterized by its method of cooling.

In an article on Constant Potential Transformers, by Mr. M. O. Troy, the second part of which appears in this issue of the Review, a number of interesting developments in the perfection of the modern transformer and the limitations which engineers met with in their early work are described in detail.

Probably as interesting a feature of the article as any is that portion devoted to the selection and judging of transformers, in which it is intended to give the purchaser information as to the various characteristics, such as heating, durability and thoroughness of insulation, etc., which should be carefully considered in order that the power company may equip its line with transformers possessing properties which will lead to the highest economy in operation and afford a minimum cost for depreciation and repairs.

LOGARITHMIC CURVES

To the average engineer the term logarithm merely connotes a mathematical function appearing in many familiar formulæ, and though he may remember the definition, the reason for the existence and the true inwardness of the thing are shrouded in mystery—it is enough that numerical results can be obtained by referring to logarithmic tables. This lack of understanding, in fact, is true of mathematics in general, and is caused to a great extent by the methods usually practiced in teaching the subject; methods much to be deplored, since mathematics is as much an experimental science as any of those usually so called, and if considered as such, develops the reasoning faculties and arouses the interest in as marked a degree.

For these reasons, the article commenced in this month's Review, on logarithmic curves, by Mr. Maxwell Day, is of considerable interest and educational value. A fresh point of view has been taken of the meaning of a logarithm, which is illustrated by curves conceived as representing time tables, the underlying difference between natural and common logarithms and their properties being thereby explained. The practical bearing of the reasoning on electrical problems is pointed out and considerable profit will therefore be derived from a careful study of the article.

The nomenclature employed in the article for common and natural logarithms avoids confusion between the two kinds, as there is a radical difference between the term *log* and *ln*. This notation has the further advantage that the base, often written as a suffix, is omitted and errors in printing are therefore less likely to occur. This or a similar nomenclature might well be standardized for logarithms in this country, and a uniform mathematical notation adopted for all functions by consulting the best usage here and in other countries.

AN EXPLANATION OF SOME OF THE DIFFERENCES BETWEEN ENGLISH AND AMERICAN PRACTICE IN ELECTRICAL ENGINEERING

By J. S. Conover

Many engineers and manufacturers have often wondered why there seemed to be so little demand in England for articles which are sold in this country in large quantities. This condition is largely due to certain differences in engineering practice, and the following explanation of some of these differences may be of interest to the readers of the Review.

The early progress in the electrical lighting field in England was greatly impeded by the strict regulations imposed by the government, which made the cost of producing and distributing electricity so high as to be almost prohibitive. In the early nineties these regulations were materially modified and the electric lighting industry began to advance with considerable rapidity. One important regulation remained and is still in force, which in itself is sufficient to account for many of the differences in lighting practice between this country and England. Under this regulation practically all electric lighting wires in cities and towns, large and small, have to be placed underground. This requirement has been one of the principal factors in limiting the use of electricity for lighting purposes to cities or towns of about 20,000 inhabitants or more, as smaller towns cannot often afford the expense of an underground cable system.

Another fact which has undoubtedly had a considerable influence upon the use of electricity for lighting purposes in small towns, is that in England most of the towns were provided with a gas plant and distributing system before the advent of electricity into the lighting field. In this country such was not the case, as many of the towns of between 5,000 and 10,000 inhabitants have only come into existence within the last ten or fifteen years, and electricity has had the same chance with gas of being first in the field. In this country over 60 per cent. of the central stations generating and distributing electricity for lighting purposes are in towns of less than 5000 inhabitants.

In most of the large cities in England the distribution is by direct current at 220–240 volts, although there is a certain amount of alternating current service. Many of the large cities are now generating alternating current and transforming it in sub-stations by motor-generators or rotary converters into direct current for distribution. In the smaller cities and towns direct current distribution at 220–240 volts is almost universal, a three-wire system with 440–480 volts between outer conductors being used. In the larger cities in this country underground cables are generally used, so that the difference in practice is much less marked than in the case of smaller cities and towns in which overhead cables are mostly used, except perhaps on a few of the principal streets.

A large majority of the electric lighting plants in England are owned by the municipalities, which also own the street railway systems. In the smaller towns in which only one generating station is required, it is economy to combine the lighting and railway stations in one. It is also economical and convenient to have the generators so designed that they can be used for either class of service. This has led to a demand—which is practically unknown in this country—for direct current generators which will give about 460–480 volts as shunt machines, and which are provided with a series field so that they will give 500–550 volts when operated as compound wound machines. A machine with these characteristics can be used for either the lighting or railway service, a separate set of bus bars being provided for each class of service.

The system of street lighting generally used in England is the series multiple; that is, two lamps in series on 220–240 volts, or four in series on 440–480 volts; or the straight multiple. Series arc and incandescent systems are practically unknown. The necessity for using underground cables has probably been primarily responsible for this difference in practice, although the objection to high voltage on the lamps may also have had something to do with it.

The comparatively small amount of alternating current distribution naturally limits the demand for lighting transformers, and even this demand is different from that in this country. The underground cables necessitate the grouping of transformers and the use of larger sizes, so that the demand for transformers of under 20 kw. is very small. All lighting transformers have to be provided with ground shields, a requirement which prevents transformers of standard American construction from being used.

A very marked difference exists in the demand for meters, apart from that due to the difference in the relative proportion of alternating and direct current distribution. In this country practically all house service meters are wattmeters; in England nearly all direct current house service meters are ampere-hour meters. Where current is supplied at more than one voltage, or as is often the case, where the same company supplies alternating and direct current, there is a strong objection in this country to the use of different rates, which is necessary if only the current is measured on direct current circuits. The same difficulty exists in England, but it has not yet been looked upon there as sufficient reason for changing from the ampere hour meter to the wattmeter for direct current circuits.

Until recently the principal differences in incandescent lamps have been in the voltage and the type of base. The English demand has been primarily for voltages between 220 and 240, and the bayonet type of base. As long as the carbon filament lamp had the field to itself no difficulty was experienced in meeting the requirements, as 220-240 volt carbon lamps of fairly good life and efficiency present no great difficulties in manufacture. With the advent of metallic filaments the situation changed entirely and has become very difficult: 220-240 volt metallic filament lamps are not yet made in England on a commercial scale, and various expedients have to be used to get around this difficulty. Where alternating current is used, individual or group transformers or compensators can be employed; but the alternating current distribution is relatively small. With direct current there is no alternative at present but to burn two or more lamps in series and make the necessary changes in the wiring. This difficulty will undoubtedly lead to methods being employed in England which are quite unnecessary here.

The demand for lighting apparatus in this country and in England differs in amount as much as in character, if not more. By 1902 or 1903 most of the cities and towns in England that could support an electric lighting plant, had one. The growth of cities and towns there is very slow compared with that in this country, and very high buildings are not replacing those of moderate height; so that after the more thickly settled portions of a city or town have been supplied, the yearly demand due to expansion is relatively small. In this country the erection of very high buildings in place of those of four or five stories creates an ever and rapidly increasing demand in a given area. Furthermore, the use of electricity in England is limited more to the real need for light, and does not extend to any considerable extent into the realm of advertising. The central portion of London is fairly well lighted, from the standpoint of convenience and safety, but it is dark as compared with New York, due to the lack of brilliant advertising displays. The yearly increase in the load of the New York Edison Co. is, I believe, about 20 to 25 per cent., while the yearly increase in the total lighting load in London is not more than 5 to 10 per cent. The difference in the consumption is pretty well illustrated by the demand for incandescent lamps. The total yearly sale of incandescent lamps in this country at the present time is estimated to be about 60,000,000, whereas in England, with a population approximately one-half as great, the total yearly sale probably does not exceed 15,000,000.

In the railway field there are fewer marked differences between the practices of the two countries, although a number of quite important ones is to be noted. The most important perhaps is that of speed. In England the maximum speed for street railway cars allowed by the municipal regulations (which are generally enforced) is about twelve miles per hour. In this country, while there are regulations in most cities, they are not strictly enforced, and the average maximum speed in cities and towns is about 25 miles per hour.

To the writer's knowledge, no interurban roads using the public highways have been built in England. Whether any attempts to promote such roads have been made, is also unknown to the writer; but it is pretty certain that speeds of from 40 to 50 miles per hour, which are common in this country on the public highway, would not be permitted in England, and the authorized speeds would probably be so low as to make the service unattractive and the undertaking unprofitable.

Another regulation which tends to limit the extension of electric roads into the more thinly populated districts, is that the drop in voltage in the return circuit shall not exceed seven volts. This regulation has made the use of track boosters quite common, and even with these boosters the cost of return cables becomes a serious item on lines extending into the suburbs. The limits set for speed and for drop in voltage in the return circuit have had the effect of confining the field of the electric railway to the fairly thickly settled portions of good sized towns.

A fact which ought not to be overlooked in this connection is that the average English working man's wages gives him a very narrow margin above his bare living expenses, and he will walk a considerable distance rather than pay a car fare. This fact alone would make a failure of a street railway in an English town of a size sufficient to support a good paying road in this country.

The type of street car generally used in England differs from that used in this country, in that it is of the double deck type with seats on top. The low speed employed makes this type of car possible, and as the regulations limit the number of passengers carried to the seating capacity, this can be almost doubled without much expense or additional weight.

The usual practice in England is to string the trolley wires on the side of instead of over the middle of the track. This is done to minimize the length of brackets and to permit their use wherever possible, as they are considered more sightly than span wires. This type of overhead construction necessitates the use of a trolley with a swivel head, which design is practically unknown in this country; furthermore, the double deck car requires a special type of trolley base to prevent the trolley pole from interfering with the passengers. There is, therefore, practically no demand in England for trolleys of the types which are standard in this country.

The low speeds do not necessitate motors of as great capacity as those generally used in this country, and lower armature speeds are required. This latter requirement led first to the design of special low speed armatures to fit frames of standard American type, but lately it has resulted in the design of special motors for the English conditions. The low speeds also make it feasible to use electric brakes, which have never been employed to any extent in this country and which necessitate a different type of controller from that generally used here.

In the field of heavy traction the English practice has adhered more closely to ours. The electrical equipment of the underground roads in London is almost identical with that of the underground and elevated roads in New York. The principal difference is due to the requirement that the drop in the return circuit shall not exceed seven volts, which has necessitated the laying of insulated return circuits. Some of the surface steam roads have electrically equipped short sections of their lines, and in so doing have followed American practice very closely.

In the industrial field the difference between English and American practice is perhaps more one of degree than of character. There are very few water powers in England, and those which do exist are small and usually too far from industrial centers to be of much use. A number of steam power distributing companies have been formed within the last five or six years and some of them are proving profitable. There is a very large and flourishing one at Newcastle, which generates and distributes the bulk of the electricity used for all purposes within a radius of 25 miles. This distribution is almost, if not entirely, by underground cables, and the maximum voltage is, I believe, 20,000.

Nearly all the large industrial centers in England are fairly near to and some of them actually in good coal fields, and power stations located in these sections ought to find a good market within a comparatively small area. The growth of the demand, however, is slow, and a number of power companies have exhausted their available funds while waiting for an increase of business. New works, if near a good source of supply, will generally put in a complete electrical equipment; but the number of new works erected during a year is exceedingly small compared with those erected in this country, and in many cases it does not pay to equip existing works. Few new cotton mills, for instance, are being erected in England, and those which are being built are generally adopting the electric drive; however, very few of the old plants are changing over. An expert in the electric drive of cotton mills was in England a few years ago and visited a number of cotton mills and talked with their managers about the advantages of the electric drive. He found them very much interested in the question and quite ready to consider a change if it could be demonstrated that the change would pay. He set to work figuring it out with them and found that with their method of figuring and under their conditions it was difficult to prove that they would be justified in making the change. With other industries it is very much the same, and the growth of the electrical business in the industrial field, although quite steady, has been slow.

Competition in most lines of manufacture is very keen, and profits are generally smaller than in this country. Stockholders are very insistent upon the payment of regular dividends, and as the directors of joint stock companies are personally liable for the payment of dividends which have not been earned, they are very careful to satisfy themselves that such have been earned before authorizing their payment. The natural result of these conditions is a tendency to minimize the amount allowed each year for depreciation, and as the initial plants are generally of a very substantial character, rates of depreciation which would not be considered sufficiently high in this country are considered satisfactory in England.

Many manufacturing firms in England are just about able to pay a dividend after making the usual provisions for depreciation. Such firms cannot afford to scrap in any one year a large amount of equipment which may still be carried on their books at a fairly high figure; for if they did so, they could not show an earned dividend and consequently would not pay one. In many cases they can figure that it would pay them to scrap a portion of their existing equipment and replace it with equipment of a more modern type; but the directors are unwilling to ask the shareholders for more capital and are also unwilling to run the risk of passing or reducing their usual dividend, and are therefore forced to postpone the change until the plant has been further depreciated, or until they are able to pay for the change out of surplus earnings. Companies which are making larger profits can make such changes more quickly and can keep more up-to-date; but such companies are the exception rather than the rule. This condition has undoubtedly had a very marked bearing upon the comparative slowness with which the English manufacturers have adopted electricity as well as other modern improvements.

The difference in conditions between the two countries extends even into the field of renewal parts. A characteristic of the English is their ability to make things last a long time and continue to give good service. This is due, in some measure at least, to the fact that they usually have an ample equipment for the requirements of the service and are able to give it systematic inspection and care. One of the electrical companies in England, which has supplied a large share of the traction equipment, was not satisfied a few years ago with the amount of business in renewal parts, such as gears, pinions, bearings, etc., which it was getting, and detailed a man to canvass the situation and find out why more business in this line was not being secured, and if anyone else was getting it. This man spent about six months traveling about England, and visited practically every electric road. He reported that his company was getting its share of the business, but the trouble was that the parts did not wear out fast enough to create a larger demand for new ones. The explanation for this is very simple. The speeds, as mentioned before, are uniformly low, the moist climate minimizes the dust, and the cars are never overcrowded and they receive systematic inspection and care. Under these conditions it is natural that the wear and tear on the equipment should be much less than is generally the case in this country.

Enough has been said to show that conditions in England are very different from those which exist in this country, and that these conditions have the effect of greatly limiting the expansion of the electrical industry and the demand for electrical apparatus. If this is true of the electrical business, it seems fair to assume that it is at least to some extent true in other branches of business.

Assuming this to be the case, the English market can be classed as a very restricted one as compared with our market. A restricted market must have an effect upon those who are supplying it, and the natural result is relatively small production and a limited stock. This is just what one finds in England in nearly every branch of business. It is quite clear that a manufacturer who has a small production and carries only a very limited stock cannot afford to install the same sort of equipment as the manufacturer who has a large production and carries a large stock. The English manufacturer must then get along with the minimum equipment and have that equipment as flexible as possible.

The necessity for minimizing his equipment has forced the English manufacturer to make the best use of what he has, and in doing this he often shows great skill. In going through one of the large shipyards on the Tyne, near Newcastle, I remember being very much impressed by finding in the middle of an old and badly lighted shop with a very poor equipment of tools, a thoroughly modern 5000 h.p. triple expansion marine engine in process of construction, the height of which was so great that a hole had been made in the roof to permit of its erection. The average American manufacturer would not undertake to build saw mill engines in such a shop and with such an equipment, and yet I doubt if the best equipped shop in America could produce an individual engine of equivalent size and type, of better quality or at a lower cost. If a number of duplicates were required, the English shop would, of course, be at a great disadvantage; but in England a number of duplicates are seldom required and the manufacturers' facilities are fairly well suited to the character of the demand.

DIRECT CURRENT SERIES MOTORS

PART II

BY PROF. F. B. CROCKER AND M. ARENDT

Motor Losses

The rated output of a motor is determined by its commutation and heating limits; hence even a small reduction of the losses within the motor is of considerable importance. For example, assume the efficiency of a motor to be increased from 90 to 91 per cent., a difference of but one per cent., in which case the total loss within the motor is reduced from 10 to 9 per cent., resulting in a decrease of 10 per cent. in the heat to be radiated and a probable lowering of the temperature rise by nearly 10 per cent. Thus it is seen that the rated output of a motor depends largely upon its efficiency. The permissible output is not, however, increased 10 per cent. in the above example, because the heating effect is as the square of the current. For example, when current rises from 1.00 to 1.05, the heating effect is augmented from 1.00 to 1.1025. On the other hand, the I^2R heat is only about one-half of the total (including core losses) so that armature current and output may be

LOSSES AT RATED LOAD IN PER CENT. OF OUTPUT

Commercial Rating h.p.	Field I^2R	ARMATURE			Motor Total
		I^2R	Core	Total	
38	4.70	4.00	2.37	6.37	11.07
38	4.60	3.80	4.92	8.72	13.32
50	4.20	2.10	3.45	5.55	9.75
50	3.25	2.80	4.80	7.60	10.82
50	4.33	3.36	4.17	7.53	11.86
75	3.20	2.50	2.93	5.43	8.63
125	2.48	2.40	2.12	4.52	7.00

SEGREGATED LOSSES AT RATED LOAD IN PER CENT. OF TOTAL LOSSES

Commercial Rating h.p.	Field I^2R	ARMATURE			Ratio Field Loss to Armature Loss
		I^2R	Core	Total	
38	42	36	22	58	.74
38	35	28	37	65	.53
50	43	22	35	57	76
50	30	26	44	70	.43
70	37	28	35	63	.57
55	37	29	34	63	.59
125	36	34	30	64	.55

raised say 7 per cent. The increased output due to rise in field current would not be great because the flux usually approaches saturation at maximum current, and may be assumed to be 1 or 2 per cent. additional.

The distribution of the losses between field and armature is of wide variation. The table on page 393, taken from a paper by W. B. Potter, gives values of the loss distribution of typical railway motors. *

Rating

There are two ratings by which railway motors are commercially classified. The nominal rating of the General Electric Company is the better known. This is defined as that output which causes a temperature rise of 75° C. from a room temperature of 25° C. after an hour's run upon test stand with motor covers open and 500 volts at motor terminals. This rating is much in excess of the continuous service capacity of the motor, but it gives a convenient means of classification and is a severe test upon the mechanical qualities of the machine. In view of the prevalent use of higher voltages, a test at 550 volts in place of 500 volts would probably more nearly approach service conditions at the present time.

The continuous rating used by the Westinghouse Co. corresponds to that current which supplied continuously to the motor on a test stand will produce a temperature rise of 60° C. The voltage selected is an approximation of the average value throughout the period of starting as well as running. No attempt is made to reproduce the conditions of ventilation that obtain in actual service.

The instantaneous capacity of a railway motor is limited by its commutation; nevertheless, in well designed car equipments the motor should be able to slip the wheels under normal track conditions before the commutation limit is reached.

The rating of motors for such work must necessarily be largely arbitrary, because of the intermittent character and very variable conditions of such service. The only conclusive test is actual operation under the practical conditions of each particular road, which a shop test can only approximate in a general way. It is well, however, to have some nominal rating, as defined above, in order to estimate and compare the performance of different railway motors.

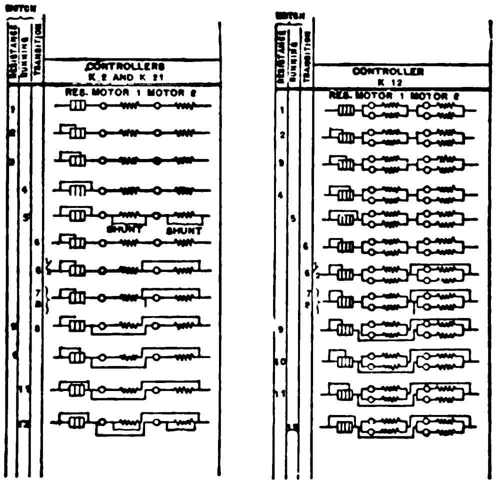
CONTROL OF DIRECT CURRENT SERIES MOTORS

Function of Controller

For all series motors, with the possible exception of those operating small fans and pumps, a starting device is necessary to increase gradually the voltage applied to motor terminals. By this means the starting current and acceleration are regulated, while the heating of the motor is restricted within reasonable limits. Starting is accomplished by inserting proper values of resistance in series with the motor either with or without different motor combinations.

Rheostat Control

The simplest form of control is by means of series rheostat or resistance which is gradually reduced in predetermined steps until the motor terminals are connected directly across the full line voltage. This method is practically the same as the rheostat control of shunt motors, except that the armature current only is affected in the latter machine. The same objections apply, however, in both cases. These include bulkiness of rheostat, widely varying speed with any considerable change in torque, and very low efficiency. For example, the loss by this control with uniform acceleration, is practically one half the total energy supplied by the line during the period of starting and thus equals the energy consumed in the motor. Moreover, the only efficient running speed is the full value.



Two Motors Four Motors

Figs. 11 and 11a. Connections of Series-Parallel Control for Two and Four Motor Equipments

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* Trans. Amer. Inst. Elect. Eng Vol. XVIV (1902) p. 170.

Series-Parallel Control

Where two or more motors or two or more windings on the same armature are to be controlled simultaneously, certain groupings may be obtained by means of which a single motor or winding receives but a fraction of the line voltage without external resistance in circuit. Thus, two motors operating together may be connected in series with each other, and in series with starting resistance which is gradually reduced until each motor receives one-half line voltage. The motors may then be thrown in parallel with each other and in series with resistance which is again cut out in steps until each motor receives full voltage. Thus there are two points of the control at which no resistance is in circuit. The total energy loss during the period from starting to full parallel operation is approximately one-third of the line supply or one-half of the motor consumption.

The speed of the motors when operated in series is about one-half that with the parallel connection. This series-parallel control is the method generally adopted for single cars and for multiple unit trains, whenever two or more motors are operated simultaneously. The various steps of this method of control are diagrammatically illustrated in Figs. 11 and 11a, which are respectively for two and four motor equipments.

Series, Series-Parallel, Parallel Control

When the equipment consists of four motors, it is becoming customary, especially for electric locomotives, to employ three groupings of motors in starting them, as illustrated in Fig. 12. At first the four motors are all in series (A), then two groups, each consisting of two motors in series, are connected in parallel (B), while finally the four motors are placed in multiple (C). During the first few steps of each combination, series resistance is gradually cut out of the circuit. This method secures higher efficiency than the others but necessitates more car wiring than either the simple rheostatic or series-parallel control. The energy loss with this method of control during the period of acceleration is about 3/11 of the total supply, or about 3/8 of the motor consumption. The three efficient running points are as shown in Fig. 12, and they correspond approximately to 1/4, 1/2 and full speed.

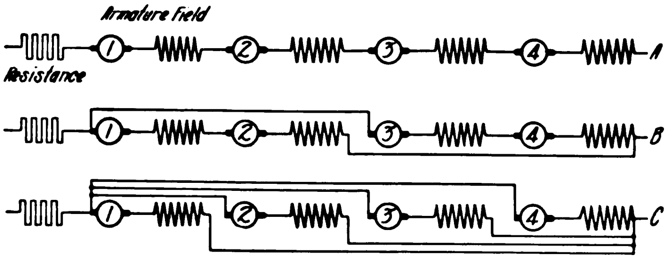

Fig. 12. Resistance Connections of the Three Runnings Points of the Series, Series-Parallel, Parallel Method of Control.

Field Control

During the early development of electric traction it was common to increase speeds after the efficient running points (without external resistance) had been reached, by shunting some of the field winding or by arranging the field coils in parallel combinations (field commutation). The resulting weakening of the field, however, led to objectionable sparking at the brushes and this form of control for railway motors was discarded. The introduction of *interpoles*, or commutating poles, which maintain a commutating flux independent of the condition of the main field, but proportional to the armature current, has revived the use of field control for high-speed railway motors.

The performance curves of a 35 h.p. series motor controlled in this manner are given in Fig. 13, while Fig. 14 illustrates the various steps of such a method of speed regulation.

The control is by series-parallel connection supplemented by the increase of speed obtainable by field weakening. After starting up with resistance as in the ordinary way, the machines are brought into the series running condition (No. 5) with full speed strength. Higher speeds are attained by combining the four field coils of each motor in partial series-parallel (No. 6), then in series-parallel (No. 7) and finally in parallel (No. 8), thus securing four field strengths for any given armature current. The speed rises as the field current is weakened but not in equal degree. Similar combinations of the field coils are employed with the parallel grouping of the motors. Thus by this method of control eight efficient running points are obtained with a two-motor equipment.

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* Article by G. H. Condict, *Electrical World*, Vol XLVII 1906, Page 1088.

The speed range at rated load, or even at any intermediate load is not, however, 8 to 1, because the field strength does not change directly with the m.m.f., the magnetic circuit being partially saturated.

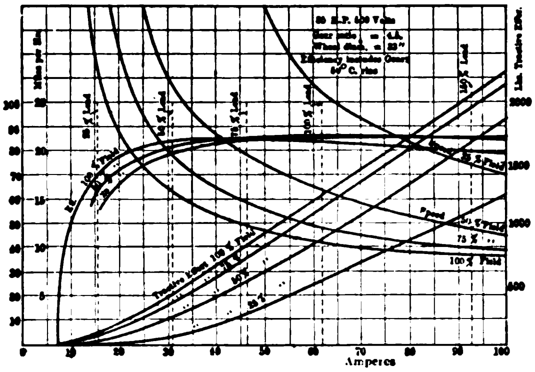


Fig. 13. Characteristic Curves of 35 H.P. Series Motor with Field Control

It is apparent from the characteristic curves of this equipment, Fig. 13, that with armature and field windings of both motors all in series, and with full field strength and rated load, the speed is about 5.2 miles per hour; while with the two motors in parallel and all field coils in parallel (weakest field condition No. 12) the speed is about 26 miles per hour, a range of 5 to 1. This is a considerable gain over the ordinary series-parallel arrangement which gives about 2 to 1 range of speed.

Drum and Master Controller

For the smaller series motors such as are used for ordinary cars, hoists, pumps, fans, etc., the power circuits are made and broken in the controller by means of stationary fingers and movable contacts mounted upon a drum or cylinder. Where large currents are required, the circuits are made and interrupted by separate switches, called contactors, which are controlled electrically from a master controller and operated by a pneumatic or solenoid device. This latter form of control is almost always used where several cars are to be operated together, and from any car irrespective of sequence. The control circuits are made continuous from the first to the last coach by means of a train line and "jumpers."

Hand and Automatic Starting

The rate of acceleration in starting depends upon how rapidly the operator moves his controller handle from the first to the last notch. Some recent types either prevent the operator from passing to the next point until the current has decreased to a certain value, or cause the controller to move ("notch up") automatically at the proper rate to a point predetermined by the operator.

The efficiency of control methods may be easily calculated, assuming that the current per motor is maintained constant by a gradual increase in voltage at the motor terminals. This is the ideal condition because it secures uniform acceleration and is closely approximated in practice with automatic starting.

A comparison of the three methods of control described above is set forth in Figs. 15, 16 and 17. In these and the formulæ accompanying them I is the current per motor, R_m is the resistance, E is line voltage and T the time from start to full speed (period of acceleration). It should be noted that the assumption made in developing these diagrams is that the time during which the

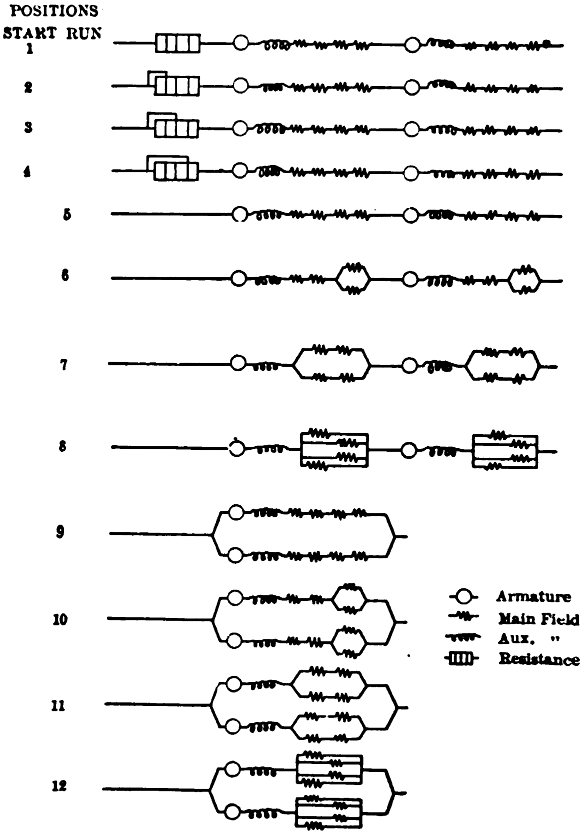
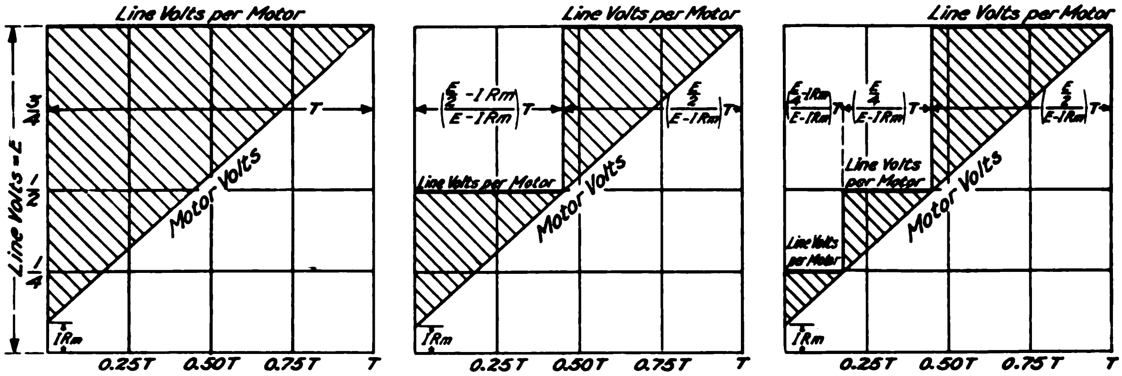


Fig. 14. Diagram of Connections Employed with Field Control of Series Motors


Line Volts per Motor
Line Volts = E
$\frac{3E}{4}$
$\frac{E}{2}$
$\frac{E}{4}$
T
Motor Volts
IRm
0.25T
0.50T
0.75T
T
Line Volts per Motor
$\frac{E}{2}-IRm$
$E-IRm$
T
$\frac{E}{2}$
$E-IRm$
T
Line Volts per Motor
Motor Volts
IRm
0.25T
0.50T
0.75T
T
Line Volts per Motor
$\frac{E}{4}-IRm$
$E-IRm$
T
$\frac{E}{4}$
$E-IRm$
T
$\frac{E}{2}$
$E-IRm$
T
Line Volts per Motor
Line Volts per Motor
Motor Volts
IRm
0.25T
0.50T
0.75T
T

	Rheostatic Control	**Series-Parallel Control**	**Series, Series-Parallel, Parallel Control**
Control Loss per Motor	$\frac{E-I\,Rm}{2}\,IT$	$\frac{\left(\frac{E}{2}-I\,Rm\right)^2+\left(\frac{E}{2}\right)^2}{2\,(E-I\,Rm)}\,IT$	$\frac{\left(\frac{E}{4}-I\,Rm\right)^2+5\left(\frac{E}{4}\right)^2}{2\,(E-I\,Rm)}\,IT$
Supply per Motor	EIT	$\frac{\frac{E}{2}\left(\frac{3E}{2}-I\,Rm\right)}{E-I\,Rm}\,IT$	$\frac{\frac{E}{4}\left(\frac{11\,E}{4}-I\,Rm\right)}{E-I\,Rm}\,IT$
Consumption per Motor	$\frac{E+I\,Rm}{2}\,IT$	$\frac{E+I\,Rm}{2}\,IT$	$\frac{E+I\,Rm}{2}\,IT$
Control Efficiency	$0.5+\frac{I\,Rm}{2E}$	$\frac{E^2-I^2\,Rm^2}{E\left(\frac{3E}{2}-I\,Rm\right)}$	$\frac{E^2-I^2\,Rm^2}{\frac{E}{2}\left(\frac{11\,E}{4}-I\,Rm\right)}$

Figs. 15, 16, 17. Diagrammatic Method of Comparing Losses in Methods of Series Motor Control

motors are in series bears the same ratio to the total time of starting as $\left(\frac{E}{2}-IR_m\right)$ bears to $(E-IR_m)$.

The shaded portion of the diagrams represents the losses during the period of starting with uniform acceleration by each of the three methods.

The following values are taken from a case in actual practice and the table below is calculated from them.

Line e.m.f. $=E=600$ volts.

Current per motor $=I=$ 250 amps.

Motor resistance, $(R_a+R_{sc})=R_m=0.14$ ohm.

Time occupied in starting $=T=30$ sec.

Number of motors $=4$.

An examination of the results set forth in the table below brings out the great advantages of the series, series-parallel, parallel control, not only as regards the greater speed range, but also the higher efficiency of the equipment during the period of starting.

COMPARISON OF DIFFERENT METHODS FOR STARTING SERIES MOTORS WITH UNIFORM ACCELERATION

Items	Rheostatic Control	Series-Parallel Control	Series, Series-Parallel, Parallel Control
Supply for 4 Motors, in kw.-sec.	18000	13800	12900
Motor Consumption, in kw.-sec.	9500	9500	9500
Total Controller Loss, in kw.-sec.	8480	4240	3340
Relative Control Losses	1.00	0.50	0.39
Relative Input to Equipment	1.00	0.77	0.72
Total Efficiency	0.53	0.69	0.74

ECONOMICAL OPERATION OF SAWMILLS AND THE MANUFACTURE OF ETHYL ALCOHOL FROM SAWDUST*

By G. U. Borde, M.E.

The fact that fuel has, up to the present time, been of such little importance to manufacturers of lumber, seems to have operated against any study of economy on the part of the owners of sawmills, as well as against the application of sound engineering principles on the part of the manufacturers of saw mill machinery.

A visit to almost any sawmill in this country shows a wastefulness that is almost criminal. Beginning in the logging camp, the timber is sacrificed; a large part of the tree is left on the ground, and nothing but waste in one form or another is seen at every step from the time the first tree is felled until the manufactured product is put on the cars.

In the mechanical equipment of any sawmill one will find that at least one third of the cost of installation is made up of shafting, boxes, pulleys and belting. The most uneconomical engines that are built have been selected to operate the plants; and I do not think that there is a single sawmill at the present day that is not obscured from view by a cloud of steam. This condition necessarily represents a large amount of wasted power.

By actual test in sawmills that I have had occasion to investigate, I have found that 30 per cent. of the entire power developed by the main sawmill engine is being wasted in turning over shafts and countershafts, to deliver but a very small percentage of its power at distant points. Another 25 per cent. is wasted in running twisted belts, bevel gears and frictions, mule pulleys, etc., which, if eliminated—and they could be by the use of electric motors—would decrease the original investment in engine and boilers by at least 50 per cent.; and further, by the elimination of all unnecessary countershafting and belts, the saving in the original investment would be decreased in that particular branch by at least 25 per cent.

It is true that the use of electricity would increase the first cost of the machinery, on account of the use of high grade apparatus. This increase, however, would be incurred for machinery on which the maintenance and depreciation is very slight, and that portion of the equipment on which the maintenance and depreciation is excessively great would be eliminated entirely.

It is a well known fact that maintenance and depreciation on boilers and their accessories is not less than 25 per cent. per annum, and this item on countershaft and belts in the ordinary sawmill is just about the same.

The amount of money spent annually for oil and belts is quite an item in the operating expenses of a sawmill. By the use of electric motors throughout, the expense for belts, oil and oilers would be decreased by at least 90 per cent., while the maintenance and depreciation of electric motors would not be over 7½ per cent.

Then again by doing away with the excessive amount of shafting required in any plant operated by steam engines, it would be possible to lessen the height of the lower floor of the sawmill and thereby at a smaller expense erect a much more substantial building. This decreased elevation of the saw floor would lower the cost of the trams throughout the yards, as well as the cost of all buildings connected thereto; and if overhead electric transfers were used throughout the mill property, the trams themselves could be entirely eliminated, the maintenance of which alone amounts annually to a large sum.

The use of individual motor drives would eliminate the terrific strain on the building supports, as there would be no shafting attached thereto; consequently, the life of the building would be thereby increased, and the cost of its maintenance and depreciation reduced.

I have had occasion to inspect a certain sawmill not over 20 years old, in which the boiler and engine plant have had to be increased on five separate occasions, without a single piece of machinery having been added, this increase in power being due entirely to the racking of the building. In fact, to-day whenever a log goes through the mill, one can readily imagine himself on board a steamer in a storm at sea. Take again the question of the transfers between the sorting chains and the kilns. Under the present system a very uneconomical engine is located about the center of the transfer, with a rope drive passing over sheaves attached to the transfer cars. It requires one man to operate the engine and another man to be on the transfer car so that it can be stopped at exactly the point required to take the kiln cars on or off. When an electric motor is used, it is placed on the transfer car and the man operating the motor can gauge his own stoppages. In addition to this extra man's wages, there would be the saving of the steam lost by condensation in the long run of pipe from the boiler to the transfer engine; and further, the motor would develop one horse-power on about 18 pounds of steam as against the present development of one horse-power on 100 pounds of steam. A still further decrease of expense would result from the reduced boiler capacity required.

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* Reprinted from the *Manufacturers' Record*.

By the use of individual electric motors driving each piece of machinery separately, it would be possible to operate any portion of the plant independently of any other portion. It would not be necessary to shut down more than one machine to change saws; or when it comes to the question of cleaning up, it would be possible to run the conveyors or any one conveyor at the will of the operator. The factor of safety both of the machinery and of the operators is increased fully 100 per cent. Should any accident occur to any piece of machinery, that individual machine could be shut down by the operator in charge in ample time to save life or property or both, as the case may be.

By eliminating the shafting and belting, which not only interfere with the proper distribution of light and air but occupy valuable space, any restriction to the location of machinery is removed. The machines can then be placed in any sequence desired, thereby avoiding the necessity of rehandling the lumber, with its attendant expense, damage and congestion. It can be readily demonstrated by laying out a plant with electric motors that the amount of floor space required is greatly reduced, and therefore the original investment in the building is reduced in proportion.

In a steam-driven sawmill operated by an engine, it is almost an absolute certainty that every time a belt slips off it is destroyed before the main engine can be shut down. I can cite a case in which this accident, without injury to any employee, has cost the owners $3500.00 in cash, to say nothing of the time lost through delay. With electric drive, should it become necessary to shut down the entire sawmill instantly, it would be possible to do so by using remote control switches located conveniently at one or any number of points throughout the entire plant, obviating the necessity of having to depend upon the engineer in charge of the engine room.

The item of insurance is materially reduced on account of the remarkable reduction in the fire hazard. The absence of a lot of belts whirling around at high speed avoids the stirring up of dust and its settling in the roof trusses where it is liable to ignite spontaneously, and in addition, the mill as a whole presents a much neater and cleaner appearance.

When all of these facts have been carefully considered, it will be found that there has been money wasted in the original installation of the sawmill; and the fact that the sawdust shavings and slabs have been considered of no value, and practically a waste product has also been the occasion of a loss of revenue. I have known cases where owners have installed additional boilers to get rid of the so-called refuse, rather than install a slab burner.

Sawdust, shavings, slabs and tree tops, however, are no longer waste products. For years the scientific world has been considering the utilization of so-called wood waste. To-day the products have assumed a commercial importance, and it may not be very many years before the lower grades of lumber will be considered as by-products, and what are to-day termed by-products, the principal aim of the owners of timber.

I have just returned from Europe where I went to investigate the manufacture of ethyl (grain, not wood) alcohol, acetic acid and stock food, out of sawdust.

In France I found that a company was organized, the aim of which was to control the entire output of the sawdust in France; which, by the way, is only the equivalent of wood waste given out by one of our sawmills having a capacity of 750,000 ft. board measure per day.

One of the principal stock holders in this concern is the largest distiller and exporter of French cognac in France, and his object in obtaining control of this company was to have the exclusive right to the alcohol made from the sawdust so that he could use it in the rectification of brandy. He admitted that he exported to England alone 50 per cent. more French cognac than the entire crop of France, and that he also sold to the balance of Europe and to the United States as well. Up to the present time he had been using alcohol made from beet sugar for the rectification. Samples of the alcohol submitted to the experts in the alcohol exchange of Paris were declared to be equivalent if not superior to the alcohol distilled from grapes: so much for the quality of the product.

The process used is one discovered by Dr. Alexander Classen of the Polytechnic School of Aachen, Aix la Chapelle, Germany, in 1900. He found that he could convert the cellulose existing in all woody fibre into a fermentable sugar by cooking the wood under pressure in the presence of sulphurous acid, and then by fermenting the sugar thus formed, obtain ethyl alcohol. This process he patented all over the world; but his original methods were crude, and the French people, after having purchased the patent rights for France, set to work to develop the process commercially. They changed the design of the apparatus suggested by Dr. Classen for the conversion, and in further experimenting found that, in addition to the sugars formed, a considerable quantity of acetic acid was produced at the same time; and so in their process they have made arrangements to extract the acetic acid as well as the alcohol.

At St. Marcel I found one of these plants in the course of construction, and the management kindly turned it over to me for experimenting. Twenty tons each of cypress shavings and long leaf yellow pine sawdust had been shipped from the South, and twenty tons of mixed hard woods from Chicago. While the plant was in course of construction enough of the apparatus was in place to carry the process through successfully, but enough was missing to prevent me from getting an absolutely accurate estimate of the cost of manufacture.

It makes practically no difference what kind of wood is used for the manufacture of alcohol, as all yield the same amount of alcohol per ton of wood. Oak, however, on account of the excessive amount of tannic acid which it contains, and which is a foe to fermentation, has to go through an additional treatment for the elimination of this acid before it can be fermented and its sugars converted into alcohol.

In a general way the process in this plant is as follows:

The sawdust, which is drawn from a radius of about 75 miles from the plant, is put into a digester, and a predetermined amount of water and sulphurous acid is added. The digester is closed and sealed and external heat applied until the pressure inside reaches about 100 pounds, at which pressure the contents are kept for a certain length of time, during which the cellulose in the wood is converted into dextrin and other sugars. The heat is then cut off and the usual sulphurous acid, which has been put into the digester simply to get the pressure to the required point, is reclaimed. The material in the digester, which has shrunk about 25 per cent., is then passed over to the separator, in which the acetic acid formed during the conversion is vaporized by means of a steam jet and then collected. The converted sawdust is then brought over to the mash tanks where its acidity is neutralized, and it is made into a mash which is fermented and distilled in the same way that an ordinary grain mash is handled in a whiskey distillery.

The tailings from the still are first compressed to extract the water and the final amount of moisture is taken out in a dryer heated by waste gases from the boilers. In France and England, these dry tailings are made into stock food or brickettes; or by the addition of a small amount of magnesia, are compressed into an artificial fireproof stone which has a crushing strength of 18,000 pounds per square inch and a tensil strength of 6000 pounds.

Other experiments are being carried on at present for further results from these tailings, and while not at liberty to make public what these experiments are, I venture to predict that there is a good deal more in the tailings than has so far been got out of them.

The results obtained from the wood shipped from America were as follows:

For every 3200 pounds of green refuse, which contains about 30 per cent. moisture and is the equivalent of one long ton of theoretically dry wood, we obtained 21½ gallons of 188° proof alcohol, which is the equivalent of 38.6 gallons of proof alcohol. By experiment in the laboratory, we found that this yield should have been about 10 per cent. higher, which loss was probably due to our inexperience in handling the apparatus.

In addition thereto will be obtained 76 pounds of acetic acid and ¾ of a ton of refuse, the latter being manufactured into stock food by the English and the French people.

The French chemist of the concern claims that under proper manipulation of the apparatus and when everything is in working order, they obtain from their wood—and we should from ours—30 gallons of alcohol per ton of sawdust.

It is estimated that for every ton of theoretically dry wood, or in other words, for every

3200 pounds of green sawdust, one should obtain:

30 gallons of 188 deg. alcohol at 40 cts. per gal.	$12.00
76 pounds of acetic acid at 6 cts. per pound.	4.56
¾ ton of stock food at $23.00 per ton	17.25
	$33.81
Less estimated cost of production	7.00
Net profit	$26.81

If one takes into consideration that 1000 feet board measure of green lumber is the equivalent of 1¼ long tons of theoretically dry wood, this would make the net return of $33.51 per 1000 feet board measure.

This to the skeptic may sound like a wild dream, but the facts given in this article are based on actual results. Some people who have had occasion to look into this matter further, have determined to go ahead and erect plants for the manufacture of alcohol, acetic acid and stock food from wood waste, and I am at present designing one plant to be erected in Hadlock, Washington, having a capacity of 50 tons of sawdust per day, and another to be erected in Ontario, Canada, with a capacity of 100 tons of sawdust per day. These plants I hope to have in successful operation by the first of the year, and the day will not be far distant when it will pay the sawmill owners to go more deeply into the question of economy of waste material in the woods, as well as waste of power in the plant.

If it is figured that so-called wood waste returns only $10.00 per ton instead of $26.81, and further, that it takes at least two tons of wood waste to equal one ton of coal in the production of steam, the sawmill owner will have to admit that the time to economize has arrived.

CONSTANT POTENTIAL TRANSFORMERS*

PART II

BY M. O. TROY

Transformer Steel

Outside of the silicon steel used by the two largest electrical manufacturers, it is believed that all of this steel manufactured in the United States comes from one source, which quite generally supplies the demands of the other manufacturers, and that the large number of silicon steels designated by such a variety of names are one and the same steel.

The use of silicon steel has assisted the transformer engineer very materially in designing transformers possessing lower core losses. The introduction of a material for transformer cores that has a loss per pound much lower than the previous standard material, has brought about a change in the limitation of design. With such a material it becomes advisable in many cases to increase core densities, and the question of proper limitations of exciting current demands consideration. An increase in the value of this current is perhaps naturally looked upon with suspicion if not with apprehension by central station managers, particularly in view of general statements which have recently appeared in the technical press. At least one or two of the large manufacturers have so zealously guarded against high exciting currents in the introduction of silicon steels that there has really been a tendency to swing to the other extreme and market transformers with needlessly low exciting currents; that is, exciting currents of lower values than those that were recognized as good engineering practice before the introduction of the silicon steel.

When a prospective purchaser considers the question of exciting currents he should bear in mind that the exciting current equals:

$$\sqrt{(\textit{magnetizing current})^2 + \left(\frac{\textit{core loss watts}}{\textit{volts}}\right)^2}$$

If then a transformer is so designed as to reduce the core loss, with the exciting current remaining constant, it is evident that to satisfy the above equation the magnetizing current must be increased. This will, of course, result in a transformer of lower power factor; but as it has the same exciting current as the one of larger core loss, and has at the same time a lower energy component, (which represents the power consumed), there is not the least doubt as to its being a more desirable transformer. Carrying out this same reasoning to a greater extent, it is evident that we may increase the exciting current over what was generally obtained in transformers the cores of which were made up of iron not containing silicon, without in any way decreasing the efficiency of the system.

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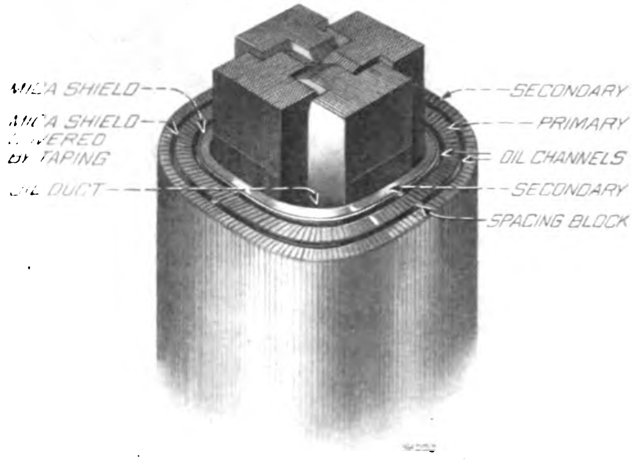
* Part I of this article appeared in the July issue of the REVIEW.

The principal effect of exciting current on the transformer is to increase the regulation drop of the transformer, but inasmuch as it is customary for the manufacturer to specify values for regulation—and this includes the effect of exciting current—it is unnecessary to take the matter up in greater detail.

Transformer Constructions

In all that has been said in the preceding portion of this article concerning lighting transformers of 50 kw. and less, the statements have been general, and not directed to any particular form of construction. A brief description of the so-called lighting transformers may be of interest, particularly some of the more modern forms. The first transformers of this type were of the so-called shell type, and consisted of primary and secondary coils wound in flat pancake sections with short winding layers and assembled one above the other. This form ultimately gave way to what was known as the two-legged core type, in which the most essential change was in the coil construction. Instead of employing flat pancake coils in this design, long cylindrical coils were adopted in which the primaries and secondaries were concentrically arranged instead of being assembled in flat sections one above the other.



Arrangement of Core, Coils and Insulation of Type H Transformers

For ease of insulation, rigidity of mechanical construction, and facility with which oil ducts could be introduced into the winding, this transformer had many advantages over the older type, and in recent years was quite generally adopted by most transformer manufacturers. The type of construction last described was more generally used than any other for a number of years. Within the last two years it has been found that this same type of coil construction—which really was the cause of success of the previous core types—when provided with a modified magnetic circuit gave even better mechanical constructions, higher efficiencies, and greater factors of safety. This modified core type is represented by the improved type "H" transformer brought out about two years ago, and the type "S" transformer more recently placed on the market. The principles of design in these two types are very similar, though they differ in the mechanical arrangement of the cores. The evolution from the two-legged core type to the distributed core type, can best be described as follows:

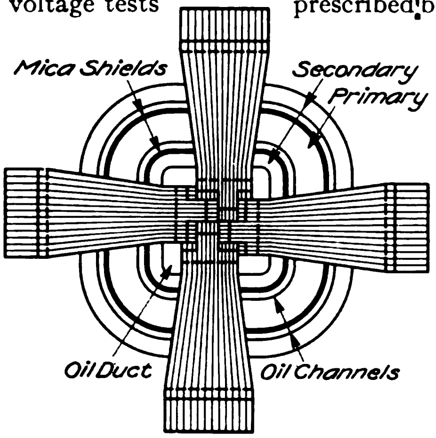
If both coils of the two-legged core type are placed on one leg of the core, we have a simplified, but unbalanced structure; that is, it is unbalanced mechanically. If the core be then split vertically into four sections and the sections swung around at angles of 90° to each other, we come to what is essentially known as the distributed core type. This simple construction would have to be modified in its mechanical arrangements and in the actual dimensions of core and coils to give the up-to-date distributed core type transformer. The essential point, however, is that the general principles of coil construction which gave the old two-legged core type its great reputation, have in general been maintained, though more ample provisions for oil ducts have been made in the modified design.

Conclusion

I will conclude this paper by a few remarks on judging a transformer; first of all, with regard to its safety. In this connection, its durability and heating are to be considered first. Taking up heating first, there is, of course, always the manufacturer's guarantee which can be checked. The heating guarantee is sometimes on increase of oil temperatures, but more generally is given on the basis of average coil temperatures, determined by the increase of resistance method as prescribed by the American Institute of Electrical Engineers. In determining the increase of temperature by increase of resistance, of course only averages are obtained. That is, it may be possible to have a transformer in which the average increase of temperature is only 10 degrees, while some point of the winding might run at a red heat. Such a transformer would evidently burn up very quickly. It becomes necessary, therefore, to look out for uniformity of heating. This is really more important than average rises. It is possible, of course, to make tests which will determine the uniformity of heating of a transformer, but it is difficult and resolves itself almost into laboratory measurements. The central station manager can usually satisfy himself by a close inspection of the designs and an observation of the provisions made therein to bring the oil into intimate relations with all portions of the copper.

Decisions based on measurements by oil temperatures are extremely questionable. Any heating guarantee given purely on the basis of oil temperatures, should be viewed with skepticism.

The next point in connection with safety is transformer insulation. Here it can be seen that the manufacturer guarantees to give the transformer the usual high potential and high voltage tests prescribed by the A.I.E.E., and this affords at least a reasonable check on the quality of the insulations as they exist at the time the transformer is bought. They do not, however, check the ability of insulations to stand up under service; that is, their ability to withstand prolonged periods of heat, the action of the oil, the miscroscopic movement of the winding due to expansion and contraction from heating, and the magnetic vibration of the transformer. The greatest safeguard here is to carefully consider the manufacturer's reputation and the quality of the product which he has heretofore placed on the market.



Plan of Type H Transformer, showing Mechanically Balanced Core

Durability is governed by the heating of the transformer, the quality of its insulations, the quality of the oil in which the transformer is submerged, and the provisions made in the construction of the transformer to exclude moisture, both before and after the transformer is placed into service. This is another point from which it is hard to judge a transformer on the basis of manufacturer's statements. To judge a transformer for its durability requires a very close inspection of the designs and can best be determined by past experience with a given construction, or preferably by a visit to the manufacturer's factory and an inspection of every detail of his processes of manufacture; *i.e.*, examining closely the quality of insulations used, and every mechanical arrangement; the provisions made to take care of the expansion and contraction of windings and to insure that the end turns of layers cannot drop down on the end turns of adjacent layers; the shield used between primaries and secondaries; and, as previously pointed out, the provisions in the design to insure uniformity of heating.

The annual cost of operation can be quite accurately determined, as previously set forth in this paper, on the basis of the manufacturer's guarantees, after assuring one's self that the product of the manufacturer meets his guarantees. The usual guarantees which come into the annual cost of operation are the core and copper losses. With regard to core losses, there is only one standard basis of measurement which gives absolute results, and that is a core loss guarantee on the basis of sine wave measurement. So-called commercial wave forms are indefinite and mean very little. In general any transformer that has its guarantees based on sine wave form will give lower core losses than guaranteed when operated on the so-called commercial wave form.

Copper loss measurements can be approximately determined by the simple wattmeter method. These measurements in general do not give the true copper loss of the transformer, but never measure less than the real copper loss. It usually measures five to ten per cent. more. . . . .

LOGARITHMIC CURVES

PART I

By MAXWELL W. DAY

The use of exponential or logarithmic functions in connection with problems of self-induction of magnets, acceleration of armatures, and many other purposes, may make a discussion of these curves of interest.

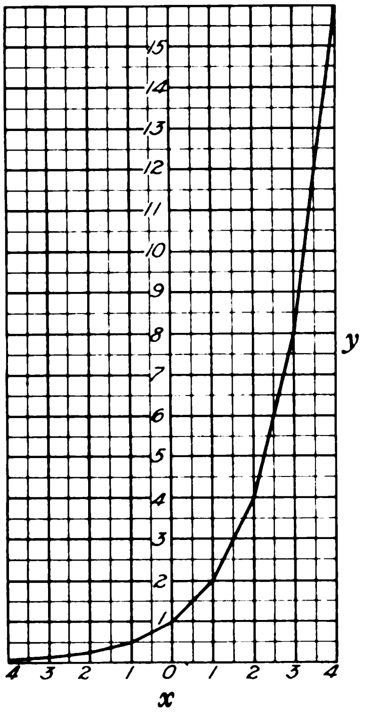


Fig. 1

The logarithm of a given number is the exponent of some other number which, when raised to the power indicated by the exponent, will equal the given number, and for all ordinary calculations the Briggs logarithms having the base 10 are used. This base is particularly convenient as it fits the Arabic system of notation with the radix 10. There is another conception of logarithms which is used in mathematical investigations and for bases other than 10.

Assume a geometrical progression plotted on paper as the ordinates of a curve, using an arithmetical progression as abscissæ. Starting at $\frac{1}{16}$ with a ratio of two, the second number will be $\frac{1}{8}$, and the others in succession will be $\frac{1}{4}$, $\frac{1}{2}$, 1, 2, 4, 8, 16, and so on. This series can be extended indefinitely in either direction, and therefore it is impracticable to start the arithmetical progression, or the values of the abscissæ, at the zero value of the ordinates. If we assume the value of x, or the abscissa, to be zero when y, or the ordinate, is equal to 1, we will have the following progression as shown in Fig. 1:

When $x=-4 \quad y=\frac{1}{16} \quad =2^{-4}$
$x=-3 \quad y=\frac{1}{8} \quad =2^{-3}$
$x=-2 \quad y=\frac{1}{4} \quad =2^{-2}$
$x=-1 \quad y=\frac{1}{2} \quad =2^{-1}$
$x=0 \quad y=1 \quad =2^{0}$
$x=1 \quad y=2 \quad =2^{1}$
$x=2 \quad y=4 \quad =2^{2}$
$x=3 \quad y=8 \quad =2^{3}$
$x=4 \quad y=16 \quad =2^{4}$

That is, in every case y is equal to 2 to the xth power, and x is equal to $log_2 y$. If the values of x began at any other point than that at which y is equal to 1, this relation would not hold.

Considering that the values of x increase uniformly, we know that when x increases by unity, that is, from 0 to 1, y increases from 1 to 2, or by an amount equal to itself at the beginning of the interval: when x increases again by unity, that is, from 1 to 2, y increases from 2 to 4, or by an amount equal to itself at the beginning of the interval. If the curve represents the value of a function which is increasing at a uniform ratio of 2, and the values of x represent time in seconds, then we can see that y increases in any one second by a value equal to itself at the beginning of that second.

If, instead of using the ratio 2, we had used 3, the successive values would have been 1, 3, 9, 27; and when x had increased by unity, y would have increased to three times its former value; that is, its increase would be twice its own value at the beginning of the interval; and if a ratio of $1\frac{1}{2}$ had been used the increase of y for each interval would have been only one-half the value of y at the beginning of the interval. In any of these cases the increase of y, for unity increase of x, *is proportional to itself;* but only in the case of the ratio 2 is this increase *equal* to its initial value.

In Fig. 2 are shown different broken lines for different ratios, extending in the value of x from 0 to 1. The line AB shows one section of Fig. 1, where the value of y increases from 1 to 2, or by an amount equal to itself when x increases by unity, that is, from 0 to 1. In the triangle ABC, AC represents the unit value of x and BC the corresponding increase of y, which is equal to the value of y at the beginning of the interval.

Instead of maintaining the uniform rate of increase for the whole unit of x (for convenience call it one second), assume that y increases by one-half of itself in the first one-half second, then one-half of its new value in the second one-half second, etc. In the triangle AED, AD represents the time during which the increase has taken place and DE the amount of increase, both being equal to 0.5 and $\frac{DE}{AD} = y$ at the beginning of the interval.

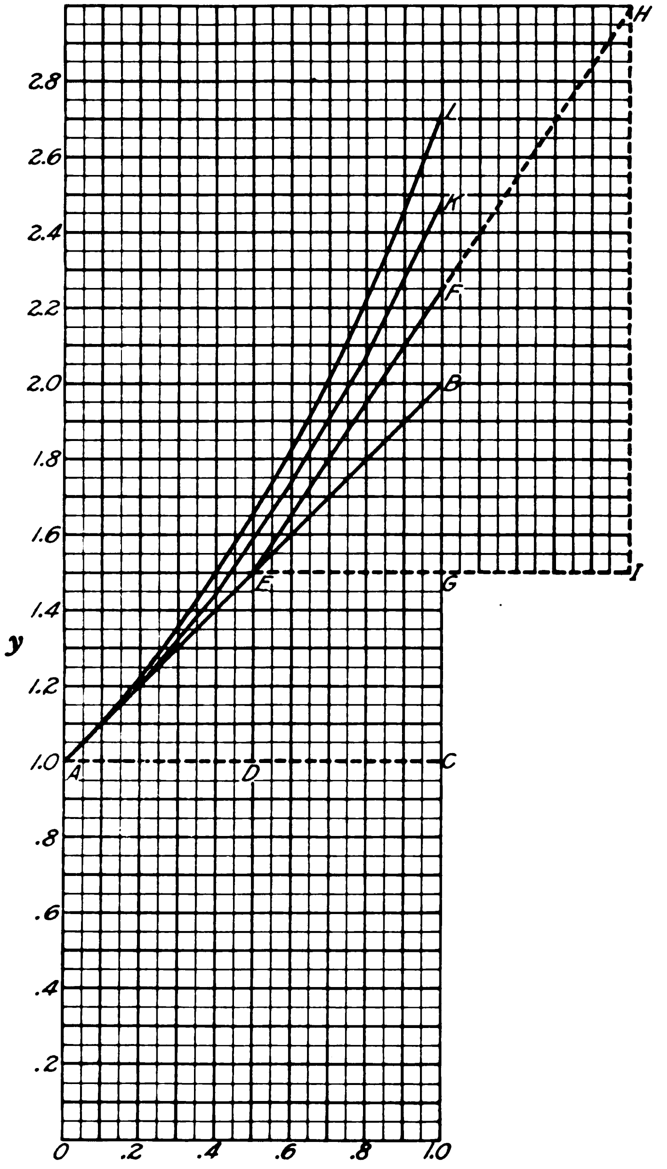


Fig. 2

In the second one-half second y increases one-half of its value; that is, from 1.5 to 2.25. In the triangle EFG, EG represents the time of increase and FG the amount of increase. In this case FG equals one and one-half times EG; *i.e.*, FG equals $y \times EG$.

Assume that the rate of increase of y continues uniform from the point E during one second: the relation will be expressed by the triangle EHI, in which EI is equal to unity and HI equals 1.5, equals y at the beginning of that interval; that is, at the point E, y is increasing at a rate equal to itself. For this condition the actual ratio of increase from A to F for one second is 2.25.

The line AK shows the condition if the change were to take place at every one-fifth second, and the total ratio of increase in one second is $1.2^5 = 2.488$.

Assume that the change of rate occurs at every one-tenth second; then, with x increasing one-tenth of unity, y will increase one-tenth of itself, and we will have the following series of values not shown in the figure:

$x = 0$ $\quad y = 1$
$x = .1$ $\quad y = 1.1$
$x = .2$ $\quad y = 1.1^2 \quad = 1.21$
$x = .3$ $\quad y = 1.1^3 \quad = 1.331$
$x = .4$ $\quad y = 1.3^4 \quad = 1.4641$
And when $x = 1$ $\quad y = 1.1^{10} \quad = 2.546$

That is, if y increases one-tenth of itself for an increase of x equal to one-tenth of unity, it will increase to 2.546 times itself in the first second and to 2.546 times that value for the second second, and so on. In other words $y = 2.546^x$.

In most mathematical investigations where a function is increasing in a manner similar to that described above, we are not given the total increase for a definite period of time, as for one second, but the rate of increase existing at any instant; and when a function increases at a rate equal to itself, it means that if the rate of increase were made constant at any point for a period of one second, the function would then increase in value an amount equal to itself; but the actual increase during a second is greater than that. Consider now that instead of dividing x into ten equal parts, it is divided into an infinitely large number of parts, n: then for each increase of x equal to $\frac{1}{n}$ of unity, y will increase $\frac{1}{n}$ of itself, and it is required to determine what will be the value of y when $x=1$.

When $x=0 \qquad y=1$

$$x=\frac{1}{n} \qquad y=1+\frac{1}{n}$$

$$x=\frac{2}{n} \qquad y=\left(1+\frac{1}{n}\right)\left(1+\frac{1}{n}\right) =\left(1+\frac{1}{n}\right)^2$$

$$x=\frac{3}{n} \qquad y=\left(1+\frac{1}{n}\right)^3$$

And when $x=\frac{n}{n}=1 \qquad y=\left(1+\frac{1}{n}\right)^n$

Expanding this by the binomial theorem we have:

$$y=1+n.\frac{1}{n}+\frac{n(n-1)}{1.2}\times\frac{1}{n^2}+\frac{n(n-1)(n-2)}{1.2.3.}\times\frac{1}{n^3}+\frac{n(n-1)(n-2)(n-3)}{1.2.3.4.}\times\frac{1}{n^4}=$$

$$1+1+\frac{n(n-1)}{2.n.n}+\frac{n(n-1)(n-2)}{2.3.n.n.n}+\frac{n(n-1)(n-2)(n-3)}{2.3.4.n.n.n.n}$$

n can be assumed to be a number so large that $\frac{n-1}{n}, \frac{n-2}{n}$, and so on for a considerable number of terms, can be made to differ from unity by less than any assignable amount. We therefore have the third term $\frac{n(n-1)}{2.n.n}=\frac{1}{2}$; the next term equals $\frac{1}{6}$, the next $\frac{1}{24}$, and so on; and

$y=1+1+\frac{1}{2}+\frac{1}{6}+\frac{1}{24}+\frac{1}{120}+\frac{1}{720}$, or expressed in decimals to six places as follows:

1.000000	
1.000000	
.500000	divide by 3
.166667	" " 4
.041667	" " 5
.008333	" " 6
.001389	" " 7
.000198	" " 8
.000025	" " 9
.000003	
2.718282	

This means that when a function increases from unity at a rate always equal to itself, it will equal 2.718282 when $x=1$, and when $x=2$, y will increase in the same geometrical proportion, and equal 2.718282^2.

This value is called ε, the base of the so called Napierian or natural logarithms, and the value of y is then expressed as being equal to ε^x.

In Fig. 2, AL represents the equation $y=\varepsilon^x$ from $x=0$ to $x=1$. This is shown further in Fig. 3.

As y increases continually at a rate equal to itself, a tangent to the curve at any point, such as where $x=0$ to the ordinate corresponding to $x=1$, and a horizontal through that point will form a right-angle triangle in which the base is equal to 1 and the height is equal to the value of y at the beginning of the interval. A tangent drawn in the other direction will meet the base line at -1, making a right-angle triangle in which the base is equal to 1, and the height is equal to

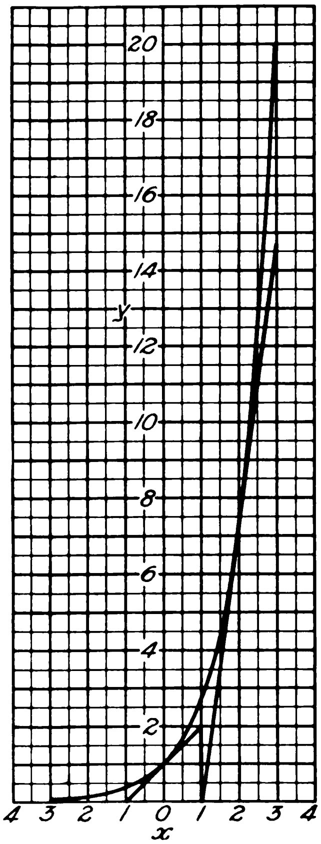


Fig. 3

y, corresponding to the value $x = 0$. A tangent from a point on the curve where $x = 2$ to the ordinate corresponding to $x = 3$, and a horizontal line drawn through that point, form a right-angle triangle in which the base is equal to 1, and the height is equal to the value of y where $x = 2$, or 7.39.

Drawn in the other direction it reaches the base line at ordinate 1, forming a right-angle triangle the base of which is equal to 1, and the height of which is equal to the value of y where $x = 2$. In all cases the sub-tangent is constant and equal to 1, and 1 is called the modulus of this system of logarithms. It means that the rate of increase of y at any point is equal to $1 \times y$ at that point.

The intersections of this curve with the vertical ordinates 1, 2, 3, 4, etc., form a geometrical progression the ratio of which is equal to ε. To the left of the prime ordinate the same relation holds true, except that the values of y are the reciprocals of the corresponding values on the right hand side. At the ordinate corresponding to $x = -2$, a tangent drawn to the next ordinate in either direction and a horizontal line drawn through that point, will form right-angle triangles the bases of which are equal to 1, and the heights of which are still equal to the values of y at the point of tangency.

The differential coefficient of any function may be expressed as the ratio of the infinitesimal increase of the function compared to the corresponding infinitesimal increment of the variable: and as the rate of increase of y is y times the rate of increase of x, then the infinitesimal increase of y, dy is equal to y times the infinitesimal increase of x, dx; that is, this relation is expressed by $dy = ydx$

$$\frac{dy}{dx} = y = tan\ a,$$

a being the tangent of the angle between the tangent to the curve and a horizontal line through the point of tangency $dx = \frac{dy}{y}$

In a table of the comparative values of x and y, in which the values of x are given corresponding to the respective values of y, the values of x indicate the time required to reach the corresponding value of y from the arbitrary starting point where $y = 1$. This table might be called a timetable of the function, and it might be written as follows:

Number	Time
1	0.0
2	0.693
3	1.099
4	1.386

However, as the law of this curve is expressed by the equation $y = \varepsilon^x$, x is the logarithm to the base ε of y and this table is, therefore, called a table of *natural* logarithms as the modulus is unity.

It is customary in many places to write the natural logarithm as log_{ε}, and the Briggs logarithms as log_{10}, where it is necessary to distinguish them; otherwise simply by the expression *log*. It is very much simpler to use, in accordance with the German practice, the abbreviation *ln* for the natural logarithms, and *log* for the Briggs logarithms. The letters *n* and *g* of the abbreviations readily distinguish the two.

The values x may represent distances in some cases, or may represent time. It is easier to consider x as representing time, each unit representing one unit of time, usually one second; and if we consider that the value of y represents the value of a function continually increasing at a rate per second equal to its value at that instant, the table of natural logarithms may be considered, not as a table of exponents, but as a time table showing the values of y at any time from the arbitrary starting point, where y is equal to one. The total time taken to change from a value less than one to a value greater than one will be equal to the algebraic sum of the negative value for logarithm of the one and the positive logarithm for the other.

By consulting a table of natural logarithms, it is found that the logarithm of 200 is 5.2983, which is the time required for y to increase in value from 1 to 200, and that the logarithm of 400 is 5.9915, which is the time required for y to increase from 1 to 400. The difference between these logarithms, 0.693, is the time required to increase from 200 to 400; but 0.693 is the logarithm of 2 representing the time required to increase from 1 to 2, so that when it is desired to find the time of increase from 200 to 400 we may take either the difference of their logarithms or the logarithm of the ratio. With a table of logarithms from 1 to 10 increasing by hundredths it is more convenient to take the ratio of the two numbers with a slide rule and obtain the logarithm of the ratio; but with a table extending from 1 to 999 by units, it may be more convenient to take the difference of the logarithms.

(To be Continued)

STREET LIGHTING OF BOSTON

By J. M. Knox

Within a very short time the city of Boston will have one of the best and by far the most economical street lighting system in the United States. Some cities there are that have a more abundant illumination—notably some of the capitals of the old world; there are others again in which the operation and maintenance cost per lamp is less, but from the point of view of efficiency—of light received for amount expended--Boston will stand pre-eminent.

Up to the time that the present system was started, the city was lighted by d.c. series enclosed arc lamps, their use dating back to 1894, when the city authorities entered into a 10 years' contract which was extended in 1904 for an additional term of 5 years. When the extension period approached the date of expiration, at which time it would become necessary to consider the question of a further extension or a new contract, the Superintendent of Streets made an extended inspection of the lighting systems in use in other cities. As a result of this investigation, he was led to believe that the trend of modern street lighting is toward greater illumination, and that, in consequence, a material improvement in the Boston system was demanded. In making this change, the goal aimed at was high, being, in fact, no less than to secure about *twice* the illumination of the old lamps *at the same cost*: a consummation devoutly to be wished, but one the possibility of which remained to be proved.

It was realized that an ideal street illumination would be one in which the light would be distributed well over the roadway with an even intensity, all dense shadows and glaring lamps being avoided; and that any variation from even intensity should consist in a relatively stronger illumination at the street corners, where the intersecting lines of travel render accidents from collisions, etc., more liable. In practice, however, it is impossible to provide an absolutely even intensity, as all lamps furnish the strongest illumination in their immediate vicinity. Therefore, to approximate as closely as possible the desired result, the lamps should emit the strongest light at those oblique angles which illuminate the areas midway between them.

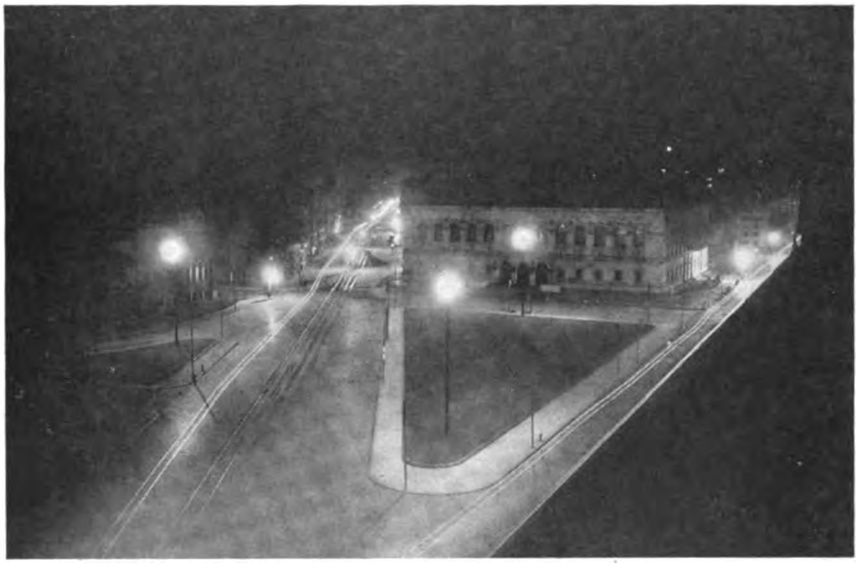


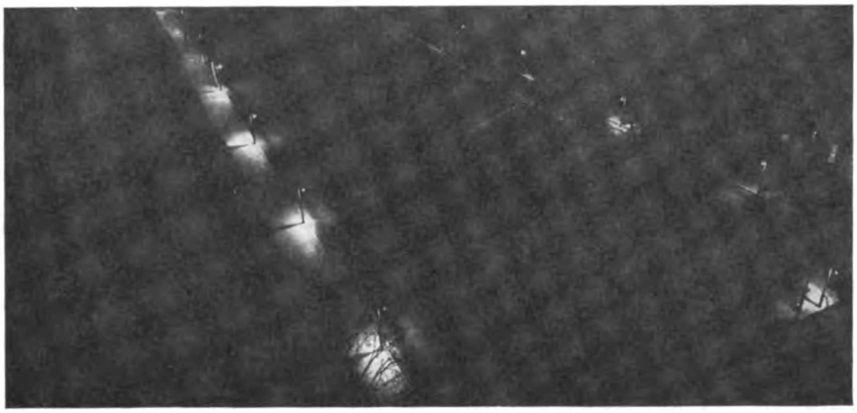
Fig. 1. Night View of Copley Square, Illuminated by G.E. Flaming Arc Lamps

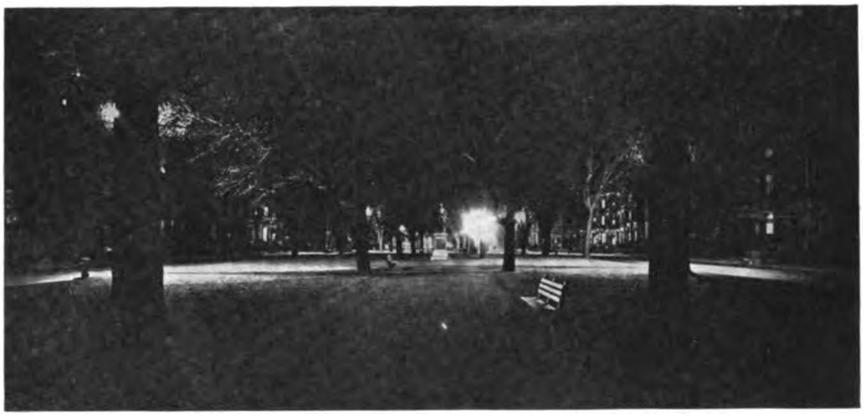
An elaborate investigation was therefore inaugurated for the purpose of selecting a system that best would meet the requirements under the conditions obtaining in Boston. For this investigation, three methods were employed: First, visits to various cities for the purpose of studying existing systems:

second, laboratory tests of apparatus; *e.g.*, photometer and distribution tests of lamps: third, the actual operation of apparatus under service conditions.

In furtherance of the first of these methods, Dr. Louis Bell made an extended tour through Europe, visiting twenty or more of the important cities of England and the Continent, and thoroughly studying the various systems in use and the conditions under which they operate. Apparatus that appeared particularly attractive was purchased and shipped to this country for test; and in this way many forms of lamps, both gas and electric, were subjected to test and comparison. Eventually this portion of the investigation narrowed itself down to two generic types; *viz.*, gas lamps and arc lamps; the former being subdivided again into low pressure and high pressure lamps, and the latter into flaming arcs and magnetite arcs.

The first of these illuminants is used with great success in both London and Berlin, although the cost is materially greater than for an equivalent illumination by electricity. Their employment in both cities is the result of special local conditions; in the former case, the exceptionally low price of gas and of labor and the absence of underground electric conduits, being the determining factors; and in the latter, the demands of labor unions and the municipal ownership of the gas plant. None of these reasons exist, of course, in the case of the city of Boston. On the contrary, the absence of high pressure ducts for carrying the gas, and the necessity for tearing up the streets for their installation should such a system be adopted, militates against the





Figs. 2 and 3, Showing a Comparison of the Illumination of Commonwealth Avenue by Low Pressure Gas Lamps and by G.E. Luminous Arc Lamps. Upper Cut, Illumination by Gas Lamps; Lower Cut, Illumination by Luminous Arc Lamps. Exposed and Developed Alike

utilization of this illuminant in the same way that the scarcity of underground conduits operates against the introduction of arc lighting in London. The main reasons, however, which influenced the authorities in deciding against the high pressure gas system were its high cost of maintenance and operation (due in a large measure to the short life of the mantels), and the fact that the lamps were more or less unreliable; being somewhat liable to accident and susceptible to material variation in candle-power with climatic changes.

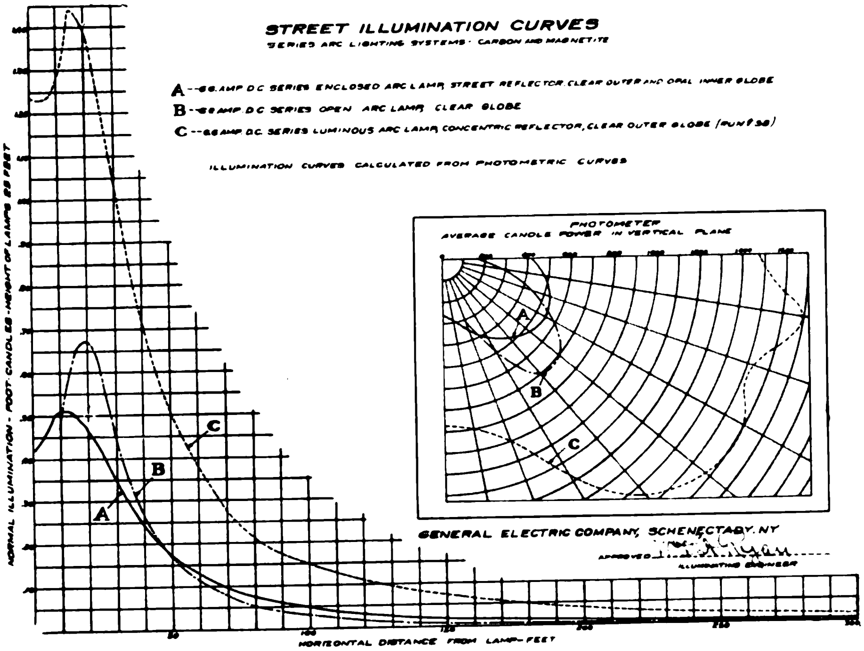


Fig. 4. Distribution of Illumination for 6.6-Ampere Direct-Current, Open, Closed and Luminous Arcs

For the purpose of testing the low pressure gas lamps under operating conditions, a demonstration installation with one of the best varieties was made on Commonwealth Avenue; but as these lamps were also found to be affected by weather conditions, their further consideration was abandoned.

With the elimination of gas lamps from the competition, the problem resolved itself into a choice between flaming and magnetite arc lamps, and the selection of the best make of lamp. At this stage of the investigation every lamp of any importance, whether foreign or domestic, was thoroughly tested out in the laboratory, and in a number of cases demonstration installations were placed on the street and tested at frequent intervals while in actual service. The final result of the entire investigation was the adoption of the General Electric Form 3 d.c. series luminous (magnetite) arc lamp, its perfect reliability and high efficiency

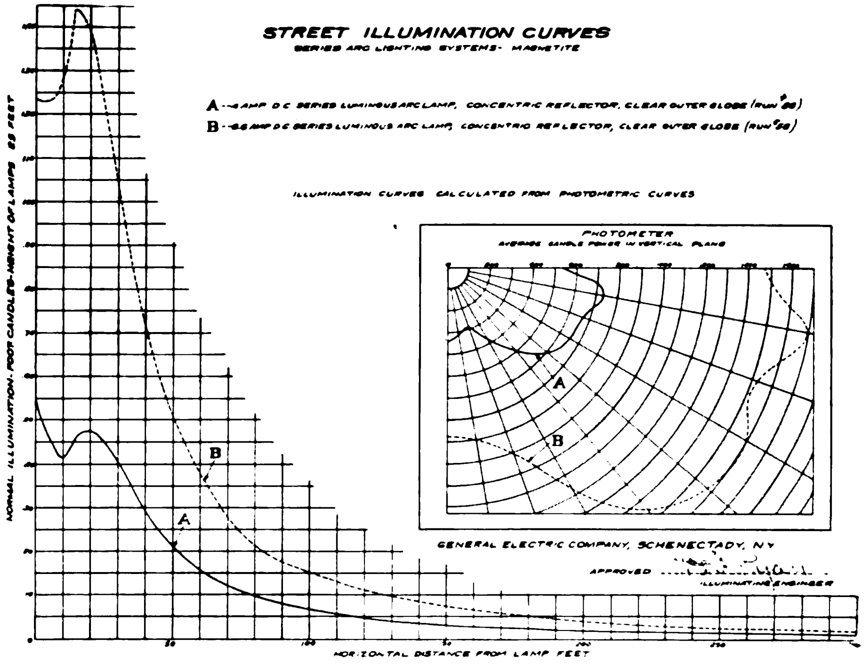


Fig. 5. Illumination Curves for Series Luminous Arc Lamps

together with the peculiarly suitable distribution of the light and its brilliant white color placing it in a class by itself.

A number of G.E. flame arc lamps will also be used for lighting certain large areas, as public squares. The old lamps were operated from Brush machines and drew 6.6 amperes. As both the new lamps, the flaming arc and the magnetite, are designed for this current, it is possible to substitute them as is convenient or desirable, and thus gradually replace the old type.

By the use of the magnetite arc, the standard of illumination which the investigators set themselves to attain has been more than realized; as instead of securing twice the light at the same cost as the old lamp, two and a half to three times the light is obtained. In view of the fact that the General Electric luminous (magnetite) lamp was selected in preference to all other competing forms of illuminants and makes of lamps, a short description may be of interest.

The essential difference between the magnetite and the carbon arc lamp lies, of course, in the electrodes. The upper one of these is simply a solid cylindrical bar of copper, which to all intents and purposes may be considered as practically permanent, its life being from two thousand to four thousand hours; its function is mainly that of a conductor. The lower electrode is the one that gives the arc its valuable characteristics; *i.e.*, extreme brilliancy and light of pure white color. It consists of a thin iron tube packed with a mixture which is largely composed of black oxide of iron, Fe_3O_4, called "magnetite." Its dimensions are ⅝ in. by 8 in., and its life is from 75 to 100 hours. As shown in Fig. 4, the lamp gives with a clear globe a maximum illumination of 1700 c.p. at 10 degrees below the horizontal—the ideal angle for street lighting. This distribution is the result of an inherent characteristic of the arc, supplemented by a specially designed reflector, the use of which was made possible by the focussing feature of the lamp. The upper electrode is stationary, while the lower electrode feeds upward to strike the arc, and is then drawn downward.

It is interesting to note the difference, as shown by these curves, between this lamp and the carbon arc, both in the matter of light distribution and that of candle-power available. As will be seen, the maximum candle-power of the enclosed arc, with clear outer and opal inner globe, is about 550, delivered at an angle of 30 degrees below the horizontal; and that of the open arc about 700 delivered at an angle of 45 degrees. Comparing these with the figures given above for the luminous arc, the superiority of the latter lamp becomes at once strikingly apparent. This conclusion is further substantiated by an inspection of Fig. 6, which shows the relative luminometer distances of the three lamps, that is, the distance from the lamp that a certain size and quality of type may be read.

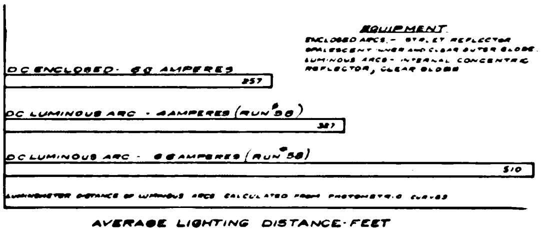


Fig. 6. Comparison of Luminometer Values of Luminous Arcs and Direct-Current Enclosed Arcs

A further comparison of these lamps, showing their relative cost of operation per year, is given in the following table.

This table does not include a large number of items that go to make up the total cost but which are approximately the same for each system; it simply shows those items, the amounts of which are affected by the differences in the systems.

*Comparative operating costs per lamp per year of 4000 hours, exclusive of repairs on overhead equipment, inspection costs, clerical and storeroom expense, etc., as these costs would be approximately the same for any modern system. Interest and depreciation are also excluded.

	6.6-Amp. D.C. Open Arc	6.6-Amp. D.C. Enclosed Arc	6.6-Amp. D.C. Luminous Arc
Energy at switchboard, 1 cent per kilowatt-hour . .	$19.68	$29.72	$29.60
Electrodes. . .	5.50	1.20	3.75
Trimming . . .	6.00	2.00	2.30
Repairs . . .	2.00	.75	.75
Outer globes . .	.30	.30	.50
Inner globes . .		.45	
Repairs and renewals on station equipment	1.50	1.50	1.50
Total . . .	$34.98	$35.92	$38.40

In the above table, it has been assumed that the lamps were operated from Brush machines, direct connected to synchronous motors. This system, however, is in no wise essential and when for any reason it is expedient to generate the power as alternating current, the lamps can be run from mercury arc rectifiers with equal facility and success.

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* Tables taken from paper presented by N. R. Birge at the Annual Meeting of the National Electric Light Association, June 4, 1909.

It frequently occurs that units of smaller candle-power than the 6.6 ampere lamps are wanted. To meet this demand a 4 ampere lamp is manufactured which is similar in every respect to the larger size, except, of course, for details of winding and for the fact that the maximum candle-power is about 700 instead of 1700. Its comparative illumination curves are shown in Fig. 5.

The table below shows the relative costs of the two sizes of lamps when operated from mercury arc rectifiers.

Here again as in the first table a large number of items are omitted, only those being considered that are influenced by the differences in the lamps.

Comparative operating cost per lamp per year of 4000 hours when operated from rectifiers; exclusive of repairs on overhead equipment, inspection costs, clerical and storeroom costs, and the like, as these costs would be approximately the same for either system. Interest and depreciation are also excluded, although the first cost of a 6.6-ampere system is about $5.00 per light higher than that of the 4-ampere system.

	6.6-Amp. 510 Watts Terminal	4-Amp. 310 Watts Terminal
Energy at switchboard, 1c. per kilowatt-hour . . .	$23.24	$14.08
Electrodes	3.75	1.70
Trimming	2.30	1.00
Repairs	.75	.75
Globes	.50	.50
Rectifier tubes	3.00	2.00
Total	$33.54	$20.03

The operating costs given above show a total per lamp of $33.54 for the 6.6-ampere unit, and $20.03 for the 4-ampere unit (exclusive of the items mentioned).

When cost per unit of effective illumination is considered, the larger units show an appreciable economy.

In every instance where these lamps have been installed they have been pre-eminently satisfactory. They have formed such an attractive proposition in cases where street lighting systems were to be rejuvenated or extended, that they have been adopted by a large number of cities throughout the United States. Among these are:—Louisville, with an installation of about 2500; Baltimore, with 1625; Fall River, with 1000; Toledo, with 1800; Portland, Oregon, with 1725; Syracuse, with 1500; Worcester, Mass., with 1000; and finally, the installation which is the subject of this article, Boston, which city has ordered 2500 and will probably add 500 more, thereby making a clean sweep and replacing all its old lamps.

SWITCHBOARD FOR UNITED STATES MINT, SAN FRANCISCO, CAL.

By D. H. Plank

The switchboard which has been designed and built by the General Electric Company for the United States mint at San Francisco, is an example of the finest switchboard construction for large office building installations and isolated private plants. For this class of service, it is the usual practice to provide a switchboard with all instruments and switches highly polished and of a design specially suited for the service required. In these respects this board is unexcelled.

The general arrangement of the switchboard is shown on page 386. The board consists of 17 panels of alberene stone, resting on a sub-base of the same material, each panel being built in two sections and supported on an angle iron frame work. The total height of the panel is 8 ft. The board is laid out to control a total of 42 two-wire, 250 volt, d.c. power and lighting circuits. The feeder panels for these two classes of service are located at the opposite ends of the switchboard and connect to separate sets of bus bars. Power is supplied from one 150 kw., and two 100 kw., 250 volt compound wound generators, which can be connected by means of selector switches to operate in multiple or separately on one or both sets of bus bars. Bulls eye indicating lamps on the generator panels, with red and green lenses, indicate to which bus the generators are connected. In addition to the generators, each bus bar can be supplied from a separate auxiliary incoming feeder of 1000 amperes capacity in case of emergency.

All circuits are protected by G.E. Type C Form P carbon break circuit breakers, in series with double break lever switches. The circuit breakers on the generator panels are of the triple-pole type, provided with low voltage attachments and reverse current time limit overload relays. To meet government specifications, the reverse current relay for the generator circuits is connected in the equalizing connection, and constitutes a feature not usually met with in ordinary practice. The circuit breakers on the incoming auxiliary feeder panels are of the double-pole type, equipped with low voltage and instantaneous overload attachments as well as reverse current and time limit relays. This latter combination is also one not usually met with in ordinary practice, but was specified by the Government. The ease with which standard circuit breakers can be adapted by means of suitable auxiliary attachments to meet varying conditions of service is well illustrated in connection with the generator and incoming line circuit breakers, where the special features demanded have been taken care of by using standard breakers and standard attachments, instead of attempting to develop circuit breakers embodying all the functions required.

The switches are made up from standard D–12 parts and follow in general the design of standard D–12 lever switches except for the double break feature, which was insisted upon by the Government engineers, although not usually required in installations of this character. The smallest switch permitted by the specifications is of 300 amperes capacity, and the result is a board of very uniform and symmetrical appearance, a feature which is of great importance in an installation of this kind. Each switch is provided with an etched copper name plate indicating the circuit which it controls; and where necessary, stops have been added to limit the throw of the switch when open. The switches on the generator and incoming feeder panels are also provided with insulating protective caps to prevent them from being accidentally closed.

All feeder circuits are wired through Type CQ recording wattmeters and G.E. Type D–2 ammeters. The wattmeters were required to be accurate within 1½ per cent. on all loads from 20 per cent. to 150 per cent. of rated load. The generator and incoming feeder panels are provided with Type CS meters. All meters are equipped with glass cases.

The voltage and total current on each set of bus bars are recorded by G.E. curve drawing voltmeters and ammeters, which are mounted on the incoming auxiliary feeder panels. At either end of the board a differential voltmeter is mounted on a swinging bracket. By means of voltmeter switches on the generator panels this voltmeter can be used to connect any generator to the bus.

All instruments, circuit breakers and supporting bolts showing on the front of the board are given a bright buffed copper finish, with the exception of the mat surface of the indicating instruments, which is finished in dull black, the contrast furnishing a very fine appearance.

The general arrangement of connections at rear of board is well shown in Fig. 1. All bus and connection bars are of ample cross section to take care of the current carried, being designed for a current density of 600 amperes per square inch. In designing the connections no bar smaller than 1½ in. by ¼ in. section was called for. All connections to the bus bars are made with triangular clamps, and all nuts on switches and circuit breakers are of copper, with special dimensions to meet government specifications. The line connections for each generator and feeder circuit are brought to suitable terminal blocks mounted on alberene stone slabs, located at the top or bottom of the board as required. This arrangement of bringing out connections is a very neat one, and is generally followed in designing boards of this class, as by so doing the unsightly appearance and crowding of the back of board with feeder cables is avoided.

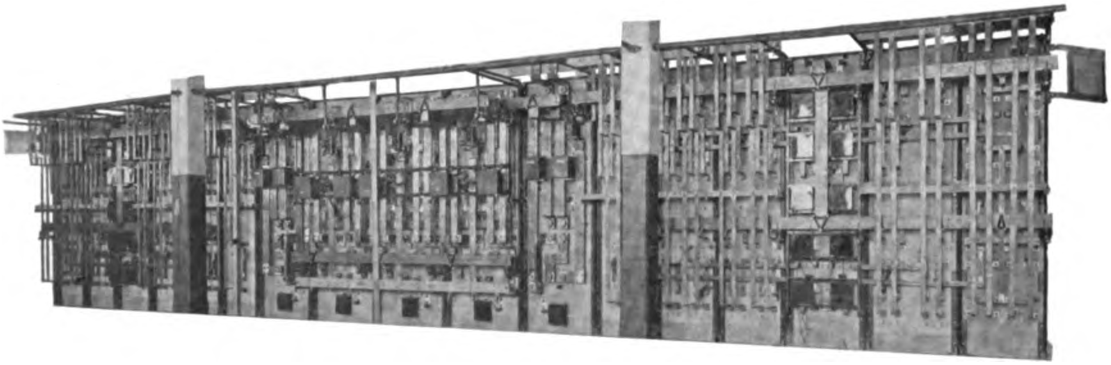

Fig. 1. Rear of Switchboard for U. S. Mint, San Francisco, Cal.

THE ELECTRIC ARC*

By R. Fleming

An arc may be defined as the column of vapor or dissociated materials between two electrodes, which carries current by virtue of the fact that the vapors—at the high temperature that is usual—are good conductors of electricity.

We shall here consider the arc at atmospheric pressure only; as at pressures higher than atmospheric, and in vaccuo, it has, in some respects, radically different characteristics, and should be treated separately.

To form an arc it is only necessary to make contact between the terminals of the circuit having suitable potential and current capacity. When the electrodes are separated, the current continues to flow across the gap and heat is generated in proportion to the energy expended in forcing the current across the gap. The points of contact are in most cases fused, and in all cases raised to a very high temperature, or to the temperature of volatilization of the material composing the electrodes.

The phenomena taking place in the arc are rather numerous and complex and have been the fruitful source of a great deal of speculation, without in any case arriving at any very definite and clear understanding of just what does happen when an arc is formed between a pair of electrodes.

The nature of the arc is largely dependent on, and influenced by the material of which the electrodes are composed. In the case of the well-known carbon arc, we have, perhaps, the simplest form. In this case we have a single material of very high purity, which fact simplifies the investigation of the chemical reactions and other phenomena that may take place. On the other hand, the carbon arc has properties peculiar to itself, which are not at all well understood and for which no satisfactory theory even has been formulated.

On close examination of the carbon arc we find: first, that both electrodes are at a high temperature, the anode, or positive electrode, being apparently very much hotter than the cathode, or negative electrode; second, that between the incandescent surfaces of the electrode there is a column of vapor, somewhat barrel shaped, through which the current passes. Scientists are agreed that the current passes from the cathode to the anode, and not in the reverse direction as is commonly supposed.

In studying the carbon arc, we shall, therefore, begin with the cathode. Here we find a comparatively small portion of the surface of the carbon at a very high temperature, the tendency of the current being to concentrate at a point. In the case of electrodes of standard dimensions and with normal current, the carbon is found to waste away rapidly at the edges. This causes the electrode to become pointed, and from the extreme tip of this point the arc plays. At first glance it would be supposed, by one to whom the normal operation of the arc was unknown, that the carbon would waste away most rapidly at this point, and it would be reasonable to suppose that here the most rapid oxidation would take place. This would hold true were it not that the carbon surrounds itself with an atmosphere of protecting gas, formed by the oxidation of the carbon surrounding the central incandescent point. It can be easily shown that when oxidation is prevented, the carbon is not actually consumed in the arc at all, but is merely vaporized and transferred from one electrode to the other, or may be deposited on the walls of the chamber surrounding the arc and on the cooler parts of the electrodes themselves. It can be shown, too, that this deposit of condensed carbon vapor has become radically changed, and is no longer in the form of ordinary amorphous carbon, but has been converted into graphite. This deposit of graphite does not take place in the ordinary arc, as the carbon vapor does not condense but is oxidized by the oxygen of the air.

There are two ways in which the phenomena of the arc stream proper may be explained: one, the purely physical one of the conduction of gases at high temperature; the other based on the theory of ionization of the gases of vapors between the electrode surfaces.

Considering the physical or merely mechanical arc, we may imagine the current leaving the cathode as generating sufficient heat to boil and vaporize the carbon over a certain small portion of the surface of the electrode. The vapor from this boiling carbon passes off into the space between the electrodes, and owing to the fact that this carbon vapor is at a very elevated temperature, it is a good conductor, merely in the sense that wire is a conductor, and without ascribing to it any property of ionization. Reasoning along these lines, we can imagine a column or wire of vapor between these two surfaces and through which current flows. Even though this vapor is a conductor, it is one of high specific resistance, and a considerable portion of the energy of the arc is expended in merely I^2R loss in this conducting vapor wire. This energy is sufficient not only to maintain the vapor at what may be called its normal saturated temperature (just as may be said in the case of water vapor); but the current passing through this vapor column superheats the vapor and raises its temperature much beyond its normal temperature at atmospheric pressure. It must be borne in mind, also, that this vapor is different from an ordinary metallic conductor in that its conductivity, instead of decreasing with increase of temperature, increases with it; in other words, has a negative temperature coefficient. This would indicate that for an increased current, the fall of potential across the arc should decrease, and this is true. Practically, if the carbon electrodes are maintained at a given distance apart and the current is increased, the fall of potential across the arc will remain fairly constant; proving conclusively that, for an increase of current through a given column of vapor, the resistance of the vapor must decrease. This property holds true, so far as known, for vapors of all materials and for gases. The specific resistance, however, of different vapors and gases vary greatly, and also the coefficient of temperature variation varies to some extent; although speaking approximately, the curve of variation of potential with current is fairly constant for a great variety of materials. Reasoning from this it follows that the center of a column of vapor between the electrodes must be the point of highest temperature and the point through which the greatest proportion of the current must flow. This property determines to some extent the luminosity of a given column of vapor, and its effect may be noticed markedly in the case of some of the so-called luminous arcs. In the case of the carbon arc the flame between the electrodes is practically non-luminous, the radiation from this vapor stream being of very high periodicity, in the blue and violet end of the spectrum. The current passing from the arc stream to the positive electrode forms what is technically known as the "crater." This crater is peculiar to the carbon arc and does not exist in the case of the metallic arcs. The crater is an intensely heated surface, of considerable area as compared with the incandescent area of the cathode. Continuing the mechanical analogy, it would seem that the resistance of the vapor close to the anode surface is higher than that at the corresponding area of contact between the cathode and the vapor column, and that consequently the energy expended and the heat generated at the former point is very much greater.

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* Paper presented before Schenectady Section A.I.E.E.

The result of this localized expenditure of energy is to heat a relatively large area of the anode carbon to the point of incandescence, or, speaking more definitely, to the vaporizing temperature of carbon. It is this incandescent surface that is known as the arc *crater;* in the case of the open arc, it forms a fairly well defined hollow, or "crater," at the tip of the carbon. The surrounding carbon oxidizes away in a manner similar to that stated as taking place at the cathode. When the carbon arc is placed in an enclosing globe this oxidation is less noticeable, as in this case the carbon edges are protected from oxygen; instead of burning to a point, the carbon tip remains flattened and is consumed quite uniformly, due to the wandering of the arc over its entire end surface.

If the theory of ionization is applied to the arc, the phenomena are described in a radically different manner from that just stated. Assuming that the current passes from the cathode to the anode, and that the carbon tips are separated the normal distance, the current in passing from the cathode into the "ionized" space between the electrodes, known as the arc stream, disrupts the surface of the carbon into the simplest elemental form, and, if we are to accept the advanced theories on the subject, into the simplest form of matter, known as "ions," or what may be called electrical charges. The particles, ions, or charges, whichever it is preferred to call them, are supposed to move bodily in the direction of the current, from the cathode to the anode. We have thus to imagine a great multitude of these "charges" flying in the direction of the anode at a very rapid rate. On striking the surface of the anode they are said to *bombard* the crater surface, delivering up their charge to the anode; and it is to this bombardment that the intense heating of the surface is due.

Neither the theory of ionization nor the merely physical theory advanced heretofore describes in a satisfactory manner what actually takes place in the arc. It is probable that neither theory accounts for the phenomenon completely, and it is quite likely that both together do not represent it even approximately. A correct explanation of the electric arc is yet to be propounded.

Besides the electrical effects taking place in the arc, there are a number of secondary actions and reactions set up, due merely to the high temperature there existing. Without paying further attention to how it is accomplished, we know that carbon is vaporized into the arc and that this carbon vapor is oxidized as fast as it is formed. There is little doubt that in the very center of the arc stream carbon vapor exists in the state of purity. This vapor is displaced by a fresh supply and passes off into the space surrounding the arc stream where it mingles with the surrounding air, combines with oxygen, and forms, first, the monoxide of carbon, CO_2 (this being the only oxide that can exist at this high temperature); then as it passes still further away from the arc stream and the temperature is reduced below 1000 or 1200 deg. C., more oxygen is taken up and C_2O formed; in this form it passes off into the surrounding atmosphere. The impurities in the arc are also vaporized, and as in most cases these impurities exist in the form of compounds of silicon, aluminum, iron, etc., they are dissociated in the arc and reduced in the presence of carbon vapor; and as they too pass out of the active zone in the center of the arc stream, they go through a process of re-oxidation The products derived from these impurities are generally deposited on the inner surface of the globe and on the metallic parts in the vicinity of the arc. In the case of the simple carbon arc, these impurities are detrimental, as they interfere with its proper working, causing unsteadiness and obscuring the light by being deposited on the glass, etc. They also interfere, to some extent, by depositing on the anode surface and diminishing the efficiency of the incandescent surface as an illuminant, probably by lowering the temperature point of vaporization, or in some similar manner.

This phenomenon just referred to is, however, taken advantage of in the case of the so-called flame arcs, by adding impurities to such an extent that the characteristics of the normal carbon arc are almost entirely obscured, and the arc takes on the characteristics of the particular salt, or compound of salts, with which the carbon is impregnated. This type of arc forms an entirely separate and distinct class and cannot strictly be considered a carbon arc, but is a step between it and the true metallic arc which will be referred to later.

The flame arc, so called, is formed between electrodes that may consist of carbon tubes having thin walls and the bore of which is filled with a mixture of powdered carbon and a variety of mineral salts. These salts are selected for the high luminous efficiency that may be obtained from burning their vapors, and the flame arc may be described as a device designed for burning these very luminous materials at a comparatively high temperature. As stated, the arc in this case loses nearly all of its carbon characteristics, the carbon is present merely as a means of conducting the current to the electrode tips, as practically all of the light giving materials are in themselves non-conductors. The material generally used is calcium in some form, owing to its high luminous efficiency in the arc, its radiation being largely within the limits of the spectrum, and to a large extent in the yellow and green. The calcium salt which has been found most satisfactory for the purpose is the fluoride, and it has also been found that the fluorides behave extremely well in the arc, much better than the oxides or other compounds. Fluorides generally give us a very steady arc free from sputtering and irregularity in operation, especially in the presence of carbon.

In these flame arcs nearly all of the light is derived from the luminous arc stream, or flame, between the electrode surfaces; and very little of the light is derived from the incandescence of the carbon tips. The more highly mineralized the electrode, the greater is the proportion of light from the flame and the smaller is the amount derived from the incandescence of the electrodes.

The electrical phenomena taking place in the arc are very nearly the same in all cases. The chemical phenomena are also quite similar, varying more or less with the nature of the material composing the electrodes.

It may be said that the materials carried into the arc, by whatever means, are dissociated into their elements at the center of the arc stream and gradually re-combine as they pass from the center to the outer zones; this recombination taking place in very much the same way as if the elements were brought together for the first time and combined by means of ordinary combustion.

Upon examination it will be found that the appearance of the arc stream in operation will change materially as the composition of the electrodes changes. In some cases, it will have considerable length between the electrodes and also considerable apparent cross section for a given amount of energy in the arc.

Flame carbons produce a large flame in the arc, while some of the metallic electrodes yield a very thin stream of vapor of very high luminous intensity. This is especially noticeable when titanium forms a part of the electrode composition.

A study of the appearance of the different arcs would indicate that the vapors of the different elements have different temperature coefficients of resistance; these coefficients are negative in all cases but vary in degree. Where the coefficient is small, the entire flame seems to act the part of conductor, giving a flame, or arc stream, of relatively large cross section and low temperature. This class is represented by the calcium and so-called flame arcs. When the coefficient is large, as in the case of titanium, the arc has the appearance of a small flexible rod, supported between the two electrode surfaces and intensely luminous.

It is interesting to speculate as to what takes place within the very center core of the arc stream, where, according to the theory just laid down, the temperature should be highest. We may ask ourselves a number of questions as to what is the means by which the current is conducted; this we have already speculated on. Also just what is the source of light in the arcs of the flame or so-called luminous type. In the flame of an ordinary candle, we are told that the luminosity is derived from particles of carbon in the process of combustion. It would appear in the case of these electric flames, as they may be called, that the same process is taking place as in the burning of the ordinary candle; that is to say, the materials are carried into the arc in the form of vapor of the different elements, are dissociated at the high temperature existing there, recombine at the cooler surface of the arc stream, and form luminous particles in the process of combustion. Thus far, we have the conditions existing in the tallow candle. There is more than this, however, in that we have to consider the heating effect of the current through the column of vapor. Are we to assume that all the light is derived merely from combustion of metallic vapors, or from the highly superheated column of vapor or gas? As a matter of fact, neither point is definitely settled, and at the present time we can only say that we do not know. In the case of some of the metallic arcs, at least, close examination of the arc stream shows an apparent dark core in the very centre of the arc, but we cannot be sure that this is not an optical illusion. We are not aided very materially in examining the arc by means of the spectroscope. In the case of the carbon arc, we get the continuous spectrum due to the incandescent solid carbon, as well as the line spectrum of whatever impurities may be in the arc at the moment. In the case of the so-called flame and metallic arcs, the spectrum is the line spectrum of vaporized materials, in some cases backed by a more or less continuous spectrum, which combination would indicate that light is derived both from the incandescent solid and incandescent vapor, a conclusion which is probably true.

The temperature of the arc is fully as perplexing as the study of its actual physical construction. Even in the case of the carbon arc, where the temperature is that due to a highly heated solid material at its boiling point, and where the temperature is evidently reasonably constant, experimenters have obtained widely different results, so that the figures are generally unreliable. In the case of the luminous arcs, there is no means by which the temperature can be measured; as no pyrometer known at the present day can measure the temperature of incandescent or burning vapors on account of the different properties of such vapors as regards their so-called selective radiation. This difference in emissivity between the different materials is very great, some materials producing an arc of very high luminous efficiency while other materials, under almost identical conditions, give us an arc that is practically non-luminous.

There are a number of electrical properties possessed by the arc that are rather remarkable. One in particular is its power, in the case of alternating current, to give the apparent effect of reactance. I have measured arcs with a power factor as low as 0.45 yet the current and e.m.f. were, strictly speaking, in phase, as they, in all cases, passed through zero at the same moment. The remarkable part is that the alternating current arc, with a non-inductive resistance in series with it, gave very much lower power factor than a similar arc with a purely inductive resistance or reactance in circuit. This phenomenon can probably be best explained in the following way:

Assuming the wave form given by the generator to be approximately a sine curve, and that a current is passed through an arc: the effect is to start the e.m.f. wave across the arc. When the current passes through zero, there is a moment when very little current is flowing. The e.m.f., consequently, will rise to a high value before the current commences to flow at all. At the point where current commences to flow, the current jumps up very rapidly, the e.m.f. falls down, and gives e.m.f. curve somewhat similar to that shown in Fig. 1.

While the e.m.f. and current waves pass through zero at the same time, to all intents and purposes, their maximum ordinates are displaced by a considerable angle, as you may see, and the power factor is a function of this displacement. This wave form distortion is particularly pronounced when a non-inductive resistance is used in series with the arc, as is the case when lamps are operated on a constant potential circuit. Such lamps require a "steadying resistance" of some sort, to take up the difference between line voltage (say 110 volts) and the voltage of the arc (70-80 volts); otherwise the arc will not maintain itself. When a reactive coil is used for this purpose, the wave form distortion is very much reduced, as is shown by Fig. 2.

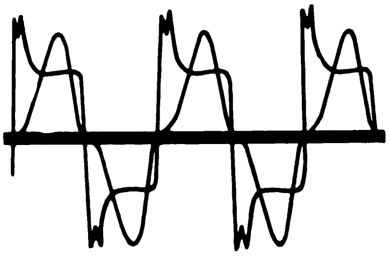


Fig. 1. Phase Displacement of Maximum Ordinates of Voltage and Current Across Arc, with Non-Inductive Resistance in Series

The pitch in the curve is due to the fact that the vapor column is cooling off, and the resistance goes up even though the current is falling; in fact this increase of resistance is the cause of such falling off. When the current is at its maximum, the resistance is lower and the voltage across the arc correspondingly lower.

With a non-inductive resistance, the current wave will be flattened out (see Fig. 1), will then rise rapidly, again fall off rapidly, and will have a similar flattening out near zero. When a reactive coil is used it stores up energy and delivers it back at the right time, preventing, or lessening, the wave distortion and displacement by helping the arc over the zero point (see Fig. 2).

The power factor of the titanium carbide arcs, measured in the secondary of a constant current transformer, is about 84 to 86. The power factor of the flame arc, so-called, having calcium fluoride and other fluorides, behaves better; the distortion there does not seem to be so great. In fact, the farther away we go from the purely metallic arc, the better the power factor with alternating current. If we design a transformer to carry say, 50 lamps, at full load and connect all the lamps up in series in such a way that the current in all cases will be passing from carbon to carbide at the same moment, we shall then get a certain value for our e.m.f. when the current is in this direction; and when the current passes from carbide to carbon we shall get a different value and very much higher one. The result would be that we would have to design the transformer for the maximum effect at that particular half wave. Now if we take half the lamps and reverse the current through them with relation to the other half, the transformer will carry about 10 per cent. more load; showing that we get a distortion effect when the current is passing from the carbon which is different from the distortion when the current is passing into the carbon. These effects are more noticeable when the current is small, and as the efficiency of these titanium lamps is very high we have need of but a very small current. The watt consumption of these lamps is very low; *viz.*, 3 amperes, with a terminal voltage of 105. The watt consumption is about 250 to 275, whereas in the old lamps, giving about one third the light, the watt consumption is from 450 to 500.

Returning to the matter of wave form: in the case of the metallic arcs there is considerable rectification taking place, especially if the two electrodes are of different materials. Take for instance what is now known as the "magnetite electrode," composed of magnetic oxide of iron mixed with titanium oxide and chromium oxide. If we try to pass an alternating current between two such electrodes we have great difficulty in causing the current to start across the arc at the zero point. If one electrode is carbon and the other of metallic material, we then have one-half of the wave very much distorted and the other half only slightly so; in this way very pronounced rectification takes place, and a considerable reading can be had on a d.c. ammeter in series with the arc. In the case of two magnetite electrodes, it would require several hundred volts to maintain any reasonable arc; whereas with direct current only about 70 volts is necessary. The reason for this discrepancy is difficult to state; it is probably due to the cooling effect of the electrodes themselves, in the first place, as they absorb quite a little heat from the very small mass of vapor. In the case of carbon, the absorption of heat is not quite so great, owing to the relatively poor thermal conductivity of the carbons themselves. It is also probable that as the temerature falls below a certain point, the resistance increases so very markedly that there is not sufficient potential to start the current at the zero point. This is not nearly so noticeable in case of very heavy arcs, and when we come to the other extreme—in the arc furnace—it practically does not exist.

Another interesting fact is, that while with the alternating current the light efficiency of the ordinary carbon arc is low,—being in many cases 30, 40 or 50 per cent. below that which can be derived from the same carbons when using direct current,—in the case of flame arcs the alternating current will give somewhat more light than will the direct. Just why this is, it is difficult to determine. It appears that the vaporization of the electrode material has to bear a certain definite relation to the current and to the cross section of the column of vapor in the arc. If there is sufficient vapor, the arc will behave well and will become very steady; but if, on the other hand, there is too much vapor, the intensity of the illumination will fall off. This probably accounts for the preceding phenomena, but how completely the writer can not state.

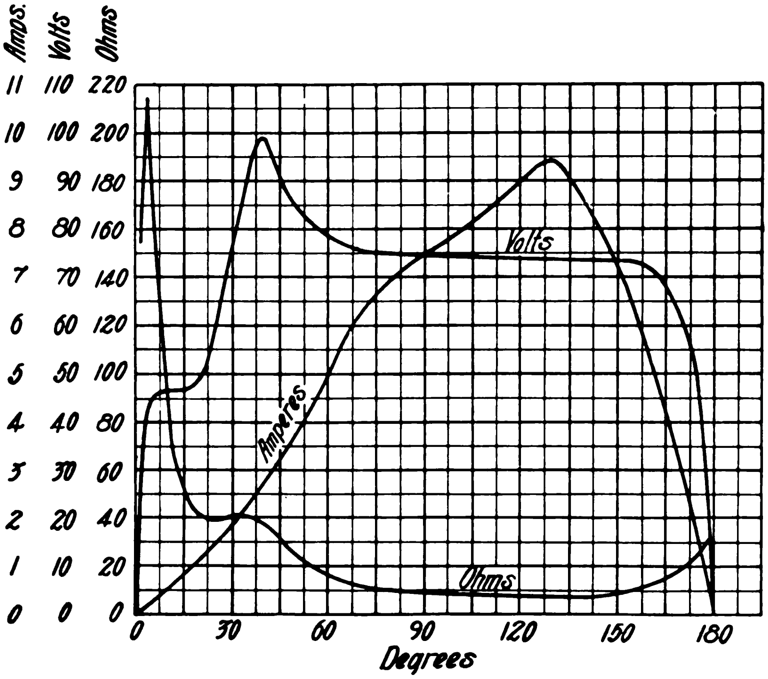


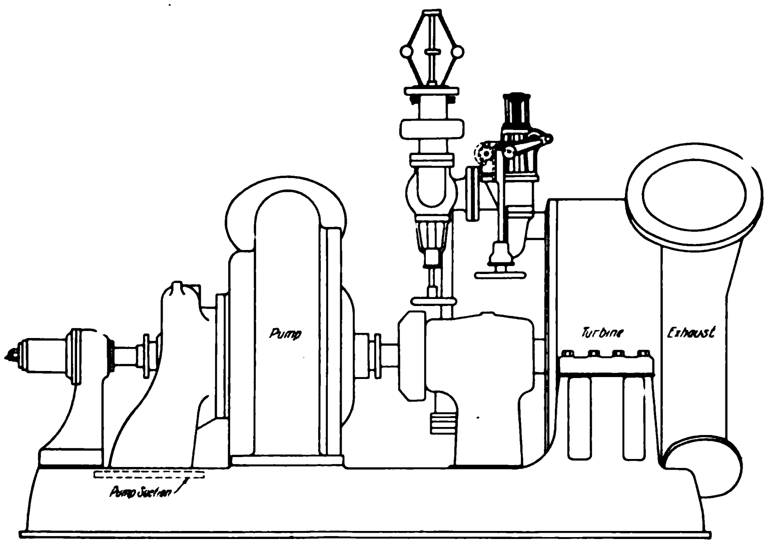
Fig. 2. Current and Voltage Phase Displacement Across Arc when Reactive Coil is Employed to Steady the Arc

It is very interesting to study the behavior of the various materials that have been or are being used in the arc lamp electrodes. The whole catalogue of elements and their compounds, and minerals of all sorts and descriptions, have been tried, and, under most conditions, the titanium compounds apparently give the greatest illuminant efficiency; the horizontal efficiency being about 0.2 watts per candle. Ordinary lime placed in the arc gives good results under some conditions, and fluoride of calcium, which is similar to the lime, gives a brilliant yellowish red tinge.

In the case of the flame arc the spherical efficiency is between 0.2 and 0.3, but the energy consumption of the arc is very much higher than that of the titanium, being between 400 and 500 watts. In the case of the flame carbon at 160 watts we get practically no light at all, because below a certain energy consumption in the arc there is apparently not enough heat generated to vaporize these materials.

DULUTH AND SAN FRANCISCO FIRE BOATS

By John Liston



Curtis Steam Turbine Driven Centrifugal Pump on Duluth Fireboat

Modern developments in the water borne commerce of both inland and seaboard cities, with the consequent increased investment in ships, wharfage, warehouses and other property on the water front, make the problem of improving the present fire fighting facilities one of great economic importance.

The extensive use of combustible materials which still characterizes American building construction, makes the relative effectiveness of different types of fire boats important factors in determining insurance rates. Where facilities exist for connecting the high pressure pumps of the fire boats to city mains, their sphere of usefulness is not limited to the immediate vicinity of the water front, and they have been found in many instances to be valuable auxiliaries to the land fire fighting apparatus.

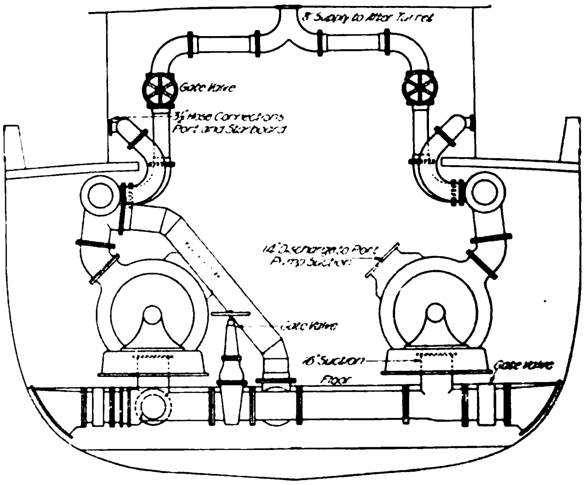
While the general tendency in fire boat construction has been in the direction of larger boats and higher water pressures, local conditions must always affect their design in regard to speed, capacity, and ice breaking and manœuvering characteristics.

The practical value of a fire boat is largely dependent on the volume and pressure of the water which can be delivered by its pumping outfit. Heretofore the usual equipment has consisted of double-cylinder, vertical, inverted reciprocating pumps, each unit having a capacity of about 3000 gallons per minute; but the high stream pressures now demanded in fire boat service can be most economically and safely obtained by the use of centrifugal pumps driven by steam turbines. This combination, when compared with the reciprocating pump equipments ordinarily used in fire boats, has the following advantages:

It shows a marked improvement in steam economy for a given amount of water delivered at the nozzles, together with a practical elimination of the strain on the hull due to vibration which is inseparable from the use of reciprocating pumps.

The absence of valves and other moving parts required in the reciprocating pump minimizes the cost of attendance and the replacement of worn parts.

The two-stage turbine-driven centrifugal pumps now in use can deliver water at higher pressure than the reciprocating pumps heretofore used, and the pressure can be

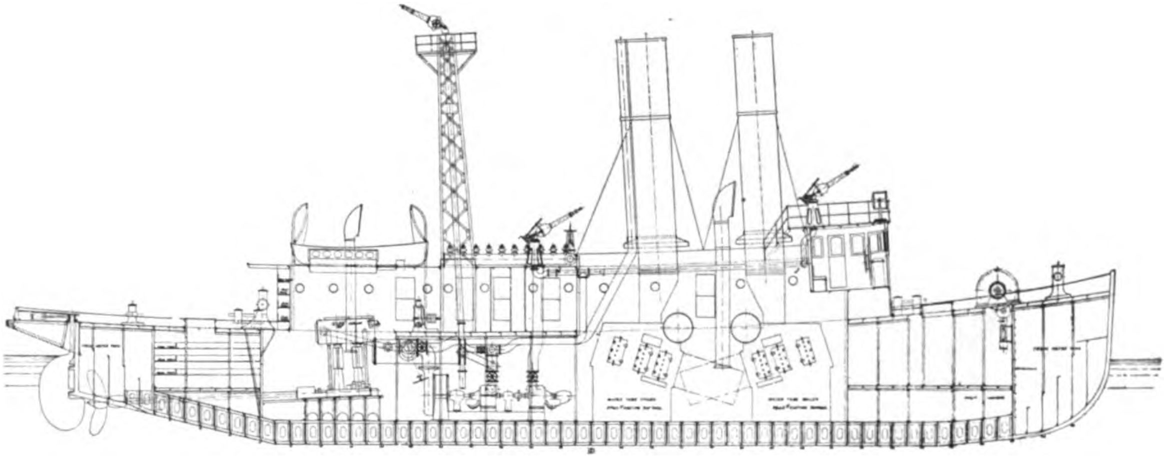

8" Supply to After Turret
Gate Valve
3½" Hose Connections Port and Starboard
14" Discharge to Port Pump Suction
Gate Valve
16" Suction
Floor
Gate Valve

Sectional View of Duluth Fireboat showing Location of Pumping Sets and Arrangement of Piping

readily increased by adding to the number of stages or by running the centrifugal pumps in tandem, without affecting the structure or general efficiency of the pumping equipment.

In order to obtain a maximum output with centrifugal pumps, high peripheral speed is necessary. The characteristics of the steam turbine make it especially valuable for this work, as it also is most efficient at speeds that are much higher than those obtained with any form of reciprocating engine.

At present five boats equipped with Curtis steam turbine driven centrifugal multi-stage pumps are in commission, distributed as follows: two each in the fire departments of New York and Chicago, and one at Duluth, which was constructed for the Duluth, Missabe and Northern Railway. In addition to these, two are now being built for the city of San Francisco.



Hull Construction and Arrangement of Machinery, San Francisco Fireboats

The pumping equipments of the New York and Chicago boats were described in the June, 1908, and Jan., 1909, editions of the Review, and the following refers only to the newer types exemplified by the boats designed for service in the waters about Duluth and San Francisco.

The details of the equipment of these boats constitute in themselves the strongest argument for their adoption by every city having water front property, which, in the event of fire, could not be readily protected by the ordinary land fire fighting apparatus.

The powerful fire boat *McGonagle*, recently completed for the Duluth, Missabe and Northern Railway, forms a notable addition to the growing fleet of fire boats that are equipped with Curtis steam turbine driven centrifugal pumps. This boat has been built to protect the iron ore docks at Duluth, Minn., and its pumps can deliver 12,000 gallons of water per minute at a pressure of 150 pounds, under normal operating conditions.

The general dimensions of the boat are: length over all 120 feet; beam moulded, 28 feet; depth moulded, 15 feet. The pumping equipment consists of two sets of two-stage centrifugal pumps, each driven by an 800 h.p., horizontal shaft Curtis steam turbine; each pumping set when supplied with steam at a pressure of 180 pounds per square inch and operating with 28 inches of vacuum, delivering 6000 gals. per min. at a pressure of 150 pounds. These two sets can be operated in series to obtain double pressure, and are tested for a pressure of 300 pounds per square inch. The compactness and accessibility of these sets, together with the general arrangement of the pumps, piping and turbines, is shown in lower cut on opposite page.

There are three main turret nozzles, one mounted on the main deck forward, one on the top of the pilot house, and the third on the top of the deck house aft. In addition to these, there are twelve valves for the auxiliary fire streams, distributed along the sides of the deck house.

The service for which this boat is intended and the waterways in which it will manœuver render the attainment of a relatively high speed desirable, and during the speed trials an average speed of about 14 miles per hour was maintained. The boat is heavily constructed and is propelled by a single screw driven by a double vertical high pressure engine having two cyclinders, each 20 inches in diameter by 24 inch. stroke. Steam at a working pressure of 180 pounds is supplied by two Scotch boilers 13 ft. 9 in. in diameter by 11 ft. 6 in. long.

The guarantees on the pumping equipment called for a steam consumption of 30,000 pounds per hour when the sets were operating at their full rated capacity, but during the exhaustive tests to which the boat was subjected before being accepted, it was demonstrated that the actual steam consumption under these conditions amounted to only 25,880 pounds per hour.

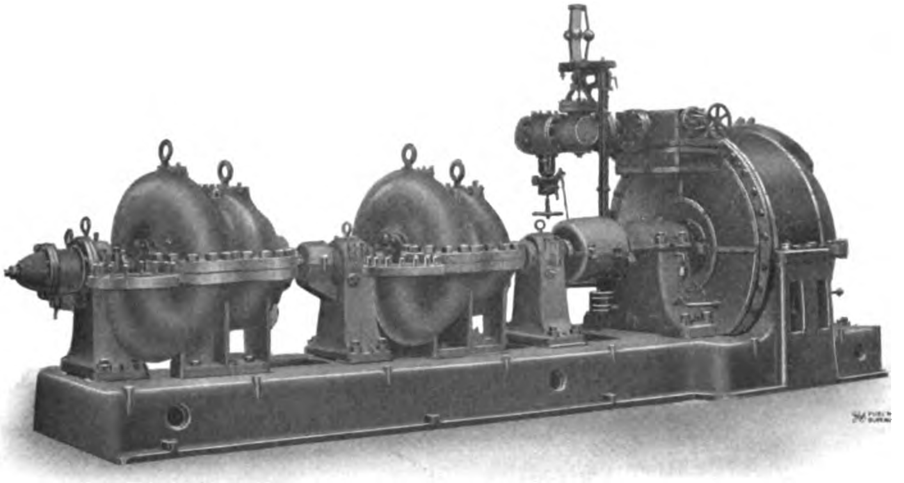
The pumps and turbines are direct connected and are mounted on a common base, their normal speed being 1800 r.p.m. The turbines are provided with both automatic and hand controlled governors, and a relief valve is also supplied to prevent injury in the event of a failure to maintain the vacuum.

Electricity is employed to light the boat, and a powerful searchlight is located on top of the pilot house, current being supplied by a 10 kw. marine generator set of General Electric manufacture.

The following non-technical description of a test of this fire boat, taken from an account which appeared in a local paper, the *Duluth News Tribune*, indicates that the *McGonagle* has fully met the requirements of her designers:

"The new fire tug, *William A. McGonagle*, owned by the Duluth, Missabe and Northern Railway, has been given a thorough test of ability to throw water.

"The big fire fighter when working at her full capacity will throw 12,000 gallons of water a minute and a stream 400 feet long. During the test the machinery and pumps worked perfectly and all who witnessed it, including members of the city fire department, officials of the city, several of the government engineering department, and a large number of citizens besides the railway officials most interested, were convinced of the tug's efficiency to do the work for which it was built."



One of the Pumping Sets for the San Francisco Fireboats Showing Two Multi-Stage Centrifugal Pumps Driven by Curtis Steam Turbine

The pumping equipment for the two fire boats, *David Scannell* and *Dennis T. Sullivan*, now being built for the San Francisco fire department, differs somewhat from that of the Duluth boat, in that each turbine is direct connected through flexible couplings to two multi-stage centrifugal pumps, all three units of each set being mounted on a common bed-plate. Two of these sets are required for each boat.

Each pump of each set is capable of delivering 2250 gallons of water per minute against a discharge pressure of 150 pounds per square inch, the two pumps of each unit being so designed that they may be operated either in parallel or in series. When operating in parallel, they deliver 4500 gallons per minute at 150 pounds pressure, and when operated in series, 2250 gallons per minute at 300 pounds pressure. These ratings apply when the suction head is zero.

The steam turbines used were manufactured by the General Electric Company and are of the same type as those built for the Duluth boat. They operate under a steam pressure of 150 pounds per square inch, and exhaust into a condenser in which a vacuum of approximately 26 inches is maintained.

In order to insure safety in operation, the turbines are provided with an automatic governor driven through positive gears from the turbine shaft. This governor is fitted with a spring which may be adjusted by hand while the turbine is running, and in this way the speed can be reduced to at least 75 per cent. of the normal without interrupting the operation of the turbine. In case the turbine speed increases 20 per cent. above normal the throttle valve immediately closes and the turbine is brought to a stop.

In view of the heavy service required of these pumping sets, and the limited space available in the hull, they were designed and constructed with special reference to making all parts accessible for overhauling, or for emergency repairs. The accompanying diagrams show the arrangement of the machinery and the compactness and accessibility of the turbine-driven pumping equipment. To insure an ample factor of safety, all parts of both pumps and turbines that are subject to internal pressure were tested with water to twice their working pressure.

The general dimensions of the boats will be: length over all, 129 feet; beam, 26 feet; depth, 12 feet, 9 inches. They are to be equipped with three main mechanically-controlled nozzles; one located above the pilot house, one amidship above the deck house, and the third mounted on a structural steel tower. The valves for the auxiliary streams are to be located amidship, above the deck house and directly above the pumping outfit; the row of valves running fore and aft.

In addition to supplying the prime movers for the pumping equipment of the San Francisco fire boats, the General Electric Company has also built for the Department of Public Works of San Francisco, eight pumping sets to be used as a land equipment in salt water pumping stations. Each of these sets consists of a horizontal shaft multi-stage turbine pump directly connected to a horizontal Curtis steam turbine, both units being mounted on a common bed plate. Each of these sets is capable of pumping 2700 gallons of salt water per minute at a pressure of 300 pounds per square inch, with a suction head of 25 feet.

FUNDAMENTAL PRINCIPLES OF RHEOSTATIC CONTROL

Part II

By A. E. Button

Industrial Control Engineering Department
General Electric Company

SPEED REGULATING RHEOSTATS

D.C. MOTORS

If the motor is required to run at a speed less than normal, a resistance is inserted in the armature circuit; but if the motor is required to run at a speed above normal, a resistance is inserted in series with the shunt field.

Armature Control

By inserting a resistance in the armature circuit the voltage on the motor terminals is reduced, and, as the speed varies directly with the voltage, a corresponding reduction in speed is obtained. This method of speed control is wasteful of energy, as the resistance dissipates as heat a large percentage of the energy taken from the mains; thus, to reduce the speed of a 1 h.p. motor 50 per cent., a resistance would be required which would dissipate ½ h.p. of energy, and the output of the motor would be reduced 50 per cent. Nor is this method of speed control suitable for motors driving machinery in which the load varies to any great extent, because the amount of speed reduction obtained by a certain resistance will vary with the load on the motor, thus producing a very unsteady drive. The motors on some kinds of machinery, such as machine tools, etc., require nearly as much current to run them at half speed as at full speed, while with other machinery, such as small job presses and ventilating fans, the current varies with the speed; thus the amount of resistance required to reduce the speed of the motor a certain amount will be different for the two classes of service. These resistances are designated as "machine" and "fan duty" rheostats.

An armature regulating rheostat, when used with a shunt wound motor, will not give the same speed reduction as when used with a series wound motor, as will be seen from an inspection of Figs. 1 and 2; but the difference will not be great enough to be noticeable, so that the same amount of resistance is generally used for shunt, compound and series wound motors.

Machine Duty

The amount of resistance required to reduce the speed a certain amount is equal to $\frac{\text{percentage reduction} \times \text{voltage}}{\text{full load current}}$; but if the load on the motor requires less than full load current, the speed reduction with the same amount of resistance will be less than with full load current, because the drop of voltage across the resistance will be less and the voltage across the motor terminals will be correspondingly greater.

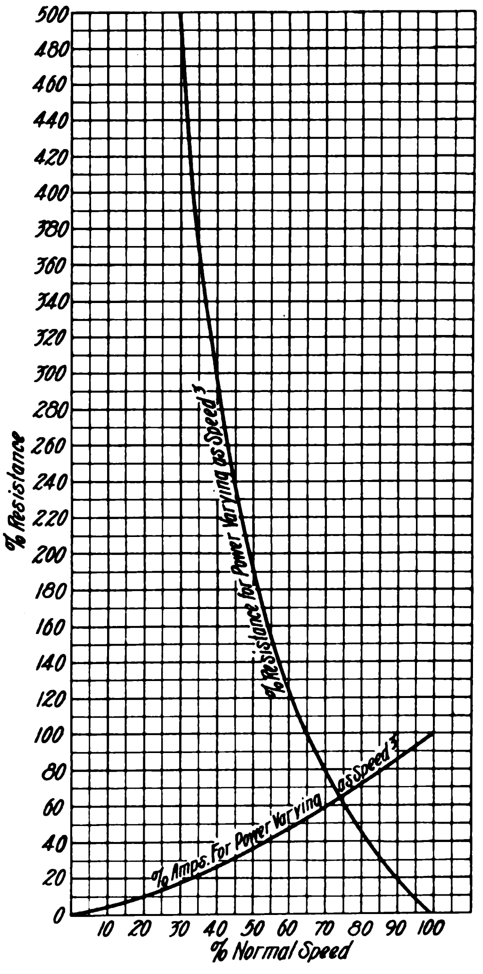


Fig. 1. Armature Resistance for Series Fan Motors. Resistance and Current in Rheostat to obtain a Certain Speed Reduction

$\frac{\text{Normal Volts Motor}}{\text{Normal Amperes Motor}} = 100\%$ Resistance

Suppose it is necessary to vary the speed of a 20 h.p., 220 volt motor driving a machine tool, from normal to 50 per cent. of normal: since the speed varies with the voltage, it will be necessary to have sufficient resistance to produce a drop of 110 volts with full load current on the motor, this resistance being designed to carry full load current on any step of the rheostat.

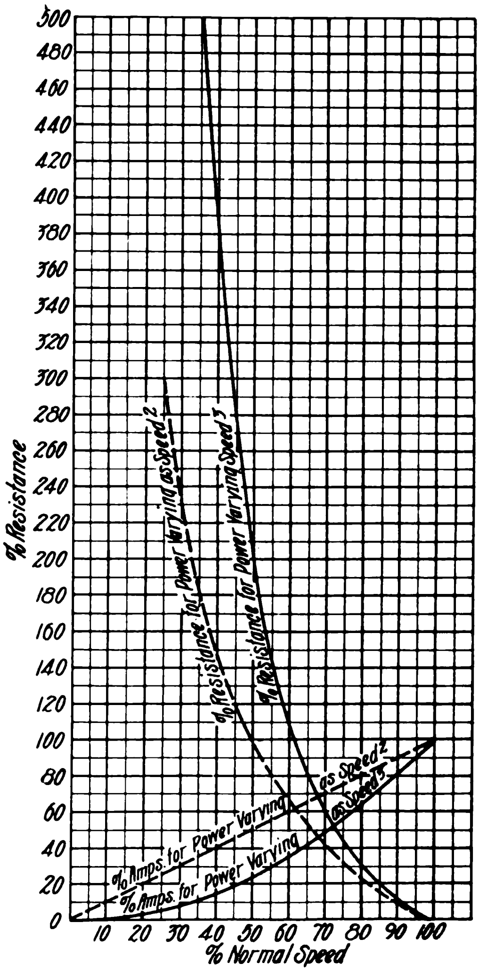


Fig. 2. Armature Resistance for Shunt Fan Motors. Resistance and Current in Rheostat to obtain a Certain Speed Reduction

$\frac{\text{Normal Volts Motor}}{\text{Normal Amperes Motor}} = 100\%$ Resistance

The full load current of a 20 h.p., 220 volt motor is 80 amps.; therefore $\frac{110}{80} = 1.38$ ohms, which is the amount of resistance required to give 50 per cent. speed reduction. Now if the load on the motor should require only 65 amps., this resistance would give less than

50 per cent. speed reduction, because 1.38 × 65 is equal to 90 volts drop on the resistance. This would give 130 volts on the motor, and the speed would equal $\frac{130}{220}$, or 60 per cent. of normal.

Motors requiring full load current at all speeds give a horse-power output in direct proportion to the speed.

The curve of Fig. 3 will give the amount of resistance required for a speed reduction of 50 per cent. from normal for shunt wound motors with different percentages of full load current.

Fan Duty

Theoretically, the energy required to operate a fan varies as the cube of the speed of the fan. That is, if the fan is running at a given speed and taking a given amount of energy, it will require eight times as much energy to operate the fan at double speed, and four times the current.

In motor-driven fans, however, and on account of the losses and disturbing conditions which come into effect at the lower speeds, it is more nearly true that the energy will vary as the square of the speed. That is, if a fan is running at a given speed and taking the normal current of the motor at this speed (no resistance being in circuit), and the speed of the motor is reduced to one-half by inserting resistance in the armature circuit, the energy necessary to operate it at this speed will be approximately one-fourth the former amount, and under ordinary operating conditions the current will be one-half the full speed current; one-half the voltage being dissipated by the resistance.

Suppose it is necessary to vary the speed of a 10 h.p., 220 volt motor, driving a fan at a speed varying from normal to 50 per cent. of normal: since the speed varies as the voltage on the motor, it will be necessary to have sufficient resistance to cause a drop of one-half the line voltage when one-half the full load current is flowing, this resistance to have a current capacity tapering from full load current to one-half of full load current.

The full load current of a 10 h.p., 220 volt motor is 40 amps.; therefore $\frac{40}{2} = 20$ amps. at reduced speed, and $\frac{110}{20} = 5.5$ ohms, or the resistance required for 50 per cent. speed.

If the horse-power of a motor at normal speed is known, the horse-power at reduced speeds is equal to $\left(\frac{r.p.m. \text{ at reduced speed}}{r.p.m. \text{ at normal speed}}\right)^2$ × horse-power.

Field Control

By inserting a resistance in series with the shunt field of the motor, a speed variation is obtained which will remain constant, independent of the load. At the same time the output of the motor remains constant at the different speeds, and very little energy is dissipated in the resistance because the current required to excite the motor fields is comparatively small. If a speed increase of more than 10 per cent. is required, a motor designed for field control is necessary; and as the resistance required

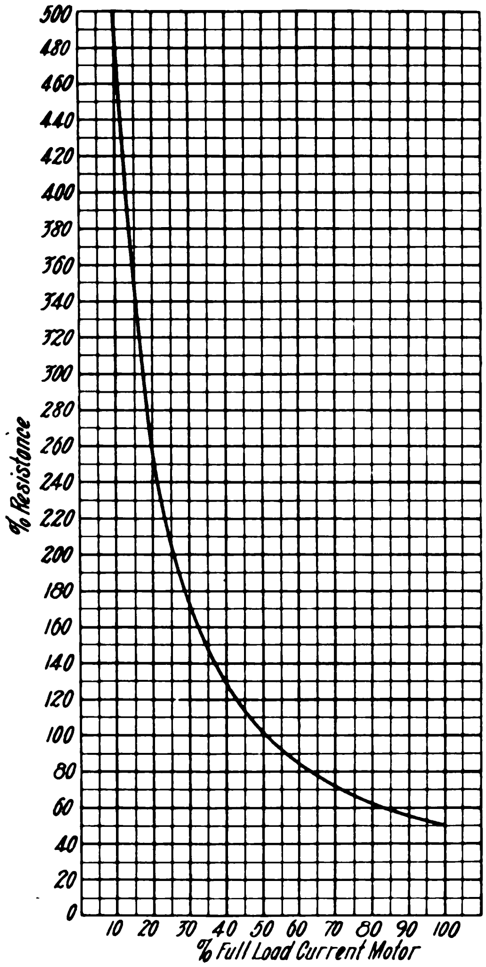


Fig. 3. Percent. Resistance Required for Shunt Motors to give 50% Speed Reduction at a Certain Percent. Full Load Current

$$\frac{\text{Normal Volts Motor}}{\text{Normal Amperes Motor}} = 100\% \text{ Resistance}$$

for a certain speed increase is different for various types of motor of the same horsepower, it is necessary to obtain from the manufacturer the rheostat data (field resistance and ohms required in rheostat) for each type of motor.

A.C. MOTORS

Where speed variation is required, it is necessary to use the slip ring type of induction motor, as the squirrel cage type of motor and the synchronous motor are not adapted for variable speed. Speed variation with slip ring type of motors is obtained by inserting a resistance in the secondary circuit and is equivalent to armature control of d.c. motors. As stated when discussing starting resistance for slip ring type of motors, the secondary voltage does not bear any fixed ratio to the primary voltage, and it is necessary to obtain the voltage between collector rings before a resistance can be laid out to give a certain speed variation. If the voltage between collector rings is known, the voltage per phase of a three-phase motor is obtained by dividing this voltage by 1.73.

$\frac{746 \times \text{h.p.}}{3}$ = watts per phase of a three-phase motor, or

$\frac{746 \times \text{h.p.}}{2}$ = watts per phase of a quarter-phase motor.

$\frac{\textit{Watts per phase}}{\textit{Secondary volts per phase}}$ = secondary amperes per phase.

$\frac{\textit{Secondary volts per phase}}{\textit{Secondary amperes per phase}}$ = resistance per phase.

This resistance is sufficient to give a speed variation from 0 to normal by adjusting the amount of resistance in circuit, provided the load is such as to require full load current in the motor. To obtain 50 per cent. reduction, one-half of the above resistance would be required. Should the load on the motor require less than full load current, the same amount of resistance would give less speed reduction.

ALLOYS

PART II

BY JOHN T. H. DEMPSTER

The trade name of "calorite" was suggested for the General Electric Company's high resistance alloy, due to its great heat resisting properties, and the name is a particularly fitting one, as will be evident when it is seen that so small a wire as 0.004 in. diam. can be maintained at red heat eight hours per day for twenty-two months: such is the record of a cigar lighter of the continuous type which has operated in the General Electric office restaurant.

Calorite is a yellowish white metal resembling german silver in color; it takes a high polish, and is perceptibly harder than wrought iron. It can be drawn down to the finest sizes of wire and has been rolled down to a thickness of 0.0025 in., but it is extremely difficult to get it below 0.003 in.; in fact, twenty-five passes through the rolls at 0.003 in. only reduces the thickness by a quarter thousandth. This is due to the extreme density and hardness which the metal has acquired in rolling. One of the first noticed characteristics of calorite was its extreme hardness when at a dull red heat, about 700 to 750° Cent.; in fact, it hammers just as hard at that temperature, apparently, as cold wrought iron, and it was found possible to make springs from calorite wire which would operate at red heat. Its tenacity is very high, wire of 0.005 in. diam. having an ultimate tensile strength of 225,000 lbs. per square inch, while in forgings of large cross sections the tensile strength, elastic limit, and ultimate breaking strength, are of about the same order as mild steel.

Calorite is chiefly remarkable for its resistance to oxidation and chemical corrosion. In a test made for oxidation, a piece of mild steel $\frac{1}{16}$ in. by 1 in. by 6 in. and a similar sized piece of calorite were placed together in a muffle furnace, so arranged that steam could be passed over the metals, which were maintained at a temperature of about 1100° Cent. The result of test showed the calorite only discolored slightly in five days, while at the end of two hours from the start, the steel had changed wholly into iron oxide. Calorite is with difficulty attacked by acids; in fact, the cold single acids do not touch it. Aqua regia or boiling dilute sulphuric acid affect it slowly. Resort had to be made to electrolysis to do the small etching required for microscope specimens.

The specific electrical resistance of calorite is considerably higher than that of any other alloy which can be commercially made into wire; it is about 70 times that of copper and 5 times that of average german silver.

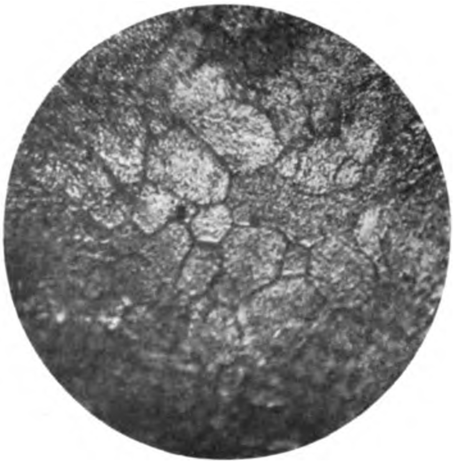


Fig. 1. Photomicrograph of Calorite Composed of 65 Parts Nickel and 15 Parts Iron

Calorite alloy is composed of approximately 65 parts of nickel, 15 of iron, 12 of chromium, and 8 of manganese. Each of these elements has an important function in the alloy, the nickel giving a non-oxidizable body to the alloy, and the iron, resistance and malleability; the chromium adds to the non-oxidizable features and tends to raise the melting point; and the manganese gives resistance and helps the ductility at red heat and for forging and rolling. Chemically all these component elements belong to the same group or have similar characteristics, such as melting points, etc. They all readily form an alloy which is permanent, and considerable changes in the percentage of the components can be made without materially changing the characteristics of the alloy; this fact, no doubt, being due to the similar natures of the components, which would not be the case with metals of different chemical groups.

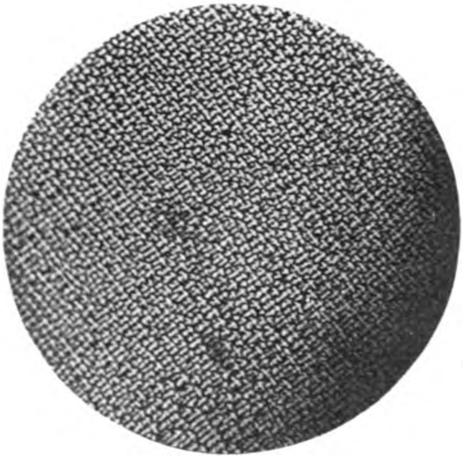


Fig. 2. Photomicrograph of a Sample of Calorite Containing a Small Excess of Carbon

The main difficulties met with in making calorite in large quantities have been those incident to melting and rolling. The alloy has a melting point of 1465±50° Cent., and as determined by the Bureau of Standards, this requires an initial temperature of the furnace considerably above this value to give the proper fluidity necessary for the alloying of the component metals.

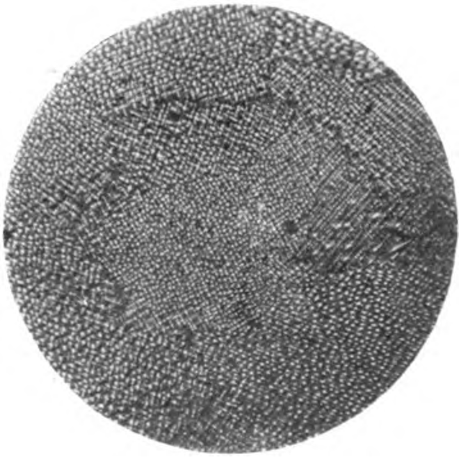


Fig. 3. Photomicrograph of Sample of Calorite Showing Different Orientation of Small Crystals with Relation to Large Crystal Faces

The oxides formed are highly basic in their nature, and it has been quite a problem to secure furnace linings which will stand. Ordinary clay lined crucibles had to be abandoned, due to the more or less acid nature of the clay lining, which was attacked and slagged away by the alloy oxides. Resort was made to the electric furnace, in which any form of lining either extremely basic or acid may be used, and the results have been entirely satisfactory. It has also resulted in reducing the melting costs about 90 per cent.

Difficulties in rolling the metal, due to carbon, sulphur, arsenic, etc., which are carried as impurities in the raw metals and which cause brittleness, hot shortness, etc., have been overcome to a large extent by a process of elimination in the furnace.

A few photo-micrographs are included herewith, which show the difference in structure between the ferro nickel and the complete alloy. Fig. 1 shows the alloy of 65 nickel and 15 iron; Fig. 2, a sample of calorite which happened to run a little high in carbon; and Fig. 3, a sample in which one particular part of the field showed the different orientation of the small crystals in relation to the large crystal faces. Calorite wire and sheet can be coated with a film of oxide, largely of chromium, which is very tenacious and will withstand a very high temperature, so that a coil wound with the turns in contact, will operate at dull red heat. Such oxide films have been built up which have withstood several hundred volts per turn. This opens up important possibilities in the way of coil winding and insulation.

Calorite is not very permeable to magnetism, but a change of about 4 per cent. in the manganese content increases its susceptibility to about that of cast iron. Its resistance temperature coefficient is such that an increase of 600° Cent. from normal increases the resistance from 10 to 15 per cent.

AN EMERGENCY WIRING JOB

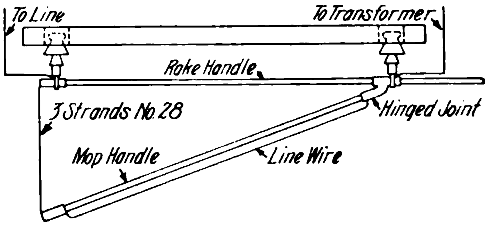
Oftentimes in cases of emergency, and when portions of equipments have been delayed in shipment or through loss or miscarriage by the transportation companies, it becomes necessary to operate electrical machinery with control apparatus of the crudest sort; and water rheostats, fuses, disconnecting switches, etc., have to be devised for construction from the material at hand.

An instance of this sort occurred recently, where the construction man was required to place in operation a bank of transformers before the proper switching apparatus, fuses, etc., had arrived.

The transformers were found standing in a temporary wooden shed and nothing in the way of equipment was to be had outside of line insulators, bare wire, and lamp cord, the last being the only insulated wire on the place. Having made a quick inventory of the local resources, three dry hard wood planks and some line insulators with wooden pins were procured; and from a local country store, three wooden rakes, three mop handles, and a copper bottom wash boiler were purchased.

Holes large enough to take the head of a line insulator were cut in the planks near the ends, and in these the insulators were cemented in place. After the cement had hardened, the planks were mounted on the side of the building. Strips of sheet copper were cut from the bottom of the wash boiler and mounted as clips on the bottom of the insulator pins. The mop and rake handles were then fitted with copper ferrules and the whole mounted as shown in the accompanying sketch.

The full load current of the transformers was in the neighborhood of 10 amperes, and three strands of No. 28 wire, taken from lamp cord, were used as a fuse. An operating platform was then built and insulated from ground with four line insulators. Inserting small pins through the upper end of the rake handle to prevent it from sliding down through the upper clip, the combined rake and mop handles were used as disconnecting switches and the transformers thus put into service. The station was operated through this improvised switchboard for several weeks until permanent apparatus was received and installed.



Improvised Disconnecting Switch and Fuse

TABLE XII

THREE-PHASE values of CHARGING CURRENT at 25 cycles per 1000 volts between two conductors.

Divide values in this table by 100. Amperes each conductor per 1000 feet of conductor (three-phase) formed by 3 parallel bare conductors.

SOLID CONDUCTORS

Interaxial Distance, Inches	0000	000	00	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	SIZE OF CONDUCTOR B & S GAUGE																		
3/8				2.670	.6738	.3290	.2366	.1870	.1562	.1348	.1248	.1068	.0958	.0898	.0831	.0778	.0728	.0684	.0648
1/2	.9560	.4200	.2780	.2098	.1707	.1452	.1268	.1128	.1022	.0935	.0864	.0806	.0741	.0706	.0666	.0632	.0601	.0572	.0548
3/4	.1885	.1568	.1353	.1196	.1073	.0978	.0898	.0831	.0778	.0728	.0686	.0648	.0608	.0586	.0561	.0536	.0514	.0494	.0476
1	.1272	.1134	.1023	.0936	.0864	.0804	.0752	.0706	.0667	.0634	.0601	.0574	.0542	.0524	.0504	.0485	.0466	.0450	.0436
2	.0753	.0708	.0668	.0634	.0602	.0575	.0548	.0526	.0504	.0485	.0468	.0450	.0432	.0421	.0408	.0396	.0385	.0372	.0363
3	.0617	.0588	.0557	.0537	.0516	.0495	.0477	.0459	.0443	.0427	.0416	.0403	.0387	.0378	.0367	.0358	.0349	.0339	.0330
4	.0550	.0526	.0506	.0486	.0468	.0452	.0436	.0421	.0408	.0396	.0385	.0374	.0361	.0352	.0345	.0336	.0327	.0319	.0310
5	.0506	.0486	.0468	.0452	.0437	.0423	.0410	.0397	.0385	.0374	.0363	.0354	.0343	.0336	.0327	.0320	.0312	.0305	.0298
6	.0477	.0459	.0443	.0428	.0416	.0403	.0390	.0378	.0368	.0358	.0349	.0340	.0329	.0323	.0314	.0307	.0301	.0294	.0287
7	.0454	.0439	.0425	.0410	.0398	.0387	.0376	.0365	.0354	.0345	.0336	.0329	.0318	.0312	.0303	.0298	.0292	.0285	.0279
8	.0436	.0421	.0408	.0396	.0385	.0374	.0363	.0354	.0345	.0336	.0327	.0320	.0310	.0303	.0298	.0290	.0285	.0278	.0272
9	.0421	.0408	.0396	.0385	.0374	.0363	.0354	.0345	.0336	.0327	.0320	.0312	.0303	.0298	.0290	.0285	.0278	.0272	.0267
10	.0410	.0397	.0385	.0374	.0365	.0354	.0345	.0336	.0329	.0320	.0312	.0305	.0296	.0290	.0285	.0280	.0272	.0267	.0261
11	.0399	.0387	.0376	.0367	.0356	.0347	.0338	.0329	.0321	.0312	.0307	.0300	.0290	.0285	.0280	.0274	.0269	.0263	.0258
12	.0390	.0379	.0368	.0358	.0349	.0340	.0330	.0323	.0316	.0309	.0301	.0294	.0287	.0281	.0276	.0270	.0268	.0260	.0254
15	.0368	.0359	.0349	.0340	.0332	.0323	.0316	.0309	.0301	.0294	.0289	.0283	.0274	.0270	.0265	.0260	.0254	.0250	.0245
18	.0354	.0345	.0336	.0327	.0320	.0312	.0305	.0298	.0290	.0285	.0278	.0272	.0267	.0261	.0258	.0252	.0247	.0243	.0238
21	.0341	.0332	.0325	.0316	.0309	.0301	.0296	.0289	.0283	.0276	.0270	.0265	.0260	.0256	.0250	.0245	.0241	.0236	.0232
24	.0330	.0323	.0316	.0309	.0301	.0294	.0289	.0281	.0276	.0270	.0265	.0250	.0254	.0250	.0245	.0240	.0236	.0232	.0229
30	.0316	.0309	.0301	.0294	.0289	.0281	.0276	.0270	.0265	.0260	.0254	.0250	.0245	.0241	.0236	.0232	.0229	.0225	.0221
36	.0305	.0298	.0290	.0285	.0278	.0272	.0267	.0261	.0258	.0252	.0247	.0243	.0238	.0234	.0231	.0227	.0221	.0218	.0214
42	.0296	.0289	.0283	.0276	.0270	.0265	.0260	.0256	.0251	.0245	.0241	.0238	.0232	.0229	.0225	.0221	.0218	.0214	.0210
48	.0289	.0281	.0276	.0270	.0265	.0260	.0254	.0251	.0245	.0241	.0236	.0232	.0227	.0223	.0221	.0218	.0214	.0210	.0207
54	.0281	.0276	.0270	.0265	.0260	.0254	.0251	.0245	.0241	.0236	.0232	.0229	.0223	.0220	.0218	.0214	.0210	.0207	.0203
60	.0276	.0270	.0265	.0260	.0254	.0251	.0245	.0241	.0236	.0232	.0229	.0225	.0220	.0218	.0214	.0210	.0207	.0203	.0201
66	.0272	.0267	.0261	.0256	.0251	.0247	.0241	.0238	.0234	.0229	.0225	.0221	.0218	.0214	.0210	.0207	.0205	.0201	.0198
72	.0267	.0261	.0258	.0252	.0247	.0243	.0238	.0234	.0230	.0226	.0222	.0219	.0214	.0212	.0209	.0205	.0202	.0198	.0196
78	.0264	.0259	.0254	.0249	.0244	.0240	.0236	.0231	.0228	.0224	.0220	.0216	.0212	.0210	.0206	.0203	.0200	.0197	.0194
84	.0261	.0256	.0251	.0246	.0241	.0237	.0233	.0229	.0225	.0221	.0218	.0214	.0210	.0207	.0204	.0201	.0198	.0195	.0192
90	.0258	.0253	.0248	.0243	.0239	.0234	.0231	.0227	.0223	.0219	.0216	.0212	.0208	.0205	.0202	.0199	.0197	.0193	.0191
96	.0255	.0250	.0245	.0241	.0237	.0232	.0228	.0225	.0221	.0217	.0214	.0210	.0206	.0204	.0200	.0198	.0195	.0192	.0189
102	.0252	.0247	.0243	.0238	.0234	.0230	.0226	.0222	.0219	.0215	.0212	.0208	.0204	.0202	.0199	.0196	.0193	.0191	.0188
108	.0250	.0245	.0241	.0236	.0232	.0228	.0224	.0221	.0217	.0213	.0210	.0207	.0203	.0201	.0198	.0195	.0192	.0189	.0187
114	.0248	.0243	.0239	.0234	.0230	.0226	.0223	.0219	.0215	.0212	.0209	.0205	.0201	.0200	.0196	.0193	.0191	.0188	.0185
120	.0246	.0241	.0237	.0233	.0229	.0228	.0221	.0217	.0214	.0211	.0207	.0204	.0200	.0198	.0195	.0192	.0190	.0187	.0184
126	.0244	.0239	.0235	.0231	.0227	.0223	.0219	.0216	.0212	.0209	.0206	.0203	.0199	.0197	.0194	.0191	.0189	.0186	.0183
132	.0242	.0237	.0233	.0229	.0225	.0221	.0218	.0214	.0211	.0208	.0204	.0202	.0198	.0196	.0193	.0190	.0188	.0185	.0182
138	.0240	.0236	.0232	.0228	.0224	.0220	.0217	.0213	.0210	.0206	.0203	.0200	.0197	.0195	.0192	.0189	.0187	.0184	.0181
144	.0239	.0234	.0230	.0226	.0223	.0219	.0215	.0212	.0208	.0205	.0202	.0199	.0196	.0194	.0191	.0188	.0186	.0183	.0180
150	.0237	.0233	.0229	.0225	.0221	.0218	.0214	.0211	.0207	.0204	.0201	.0198	.0195	.0193	.0190	.0187	.0185	.0182	.0179
156	.0236	.0232	.0227	.0224	.0220	.0216	.0213	.0210	.0206	.0203	.0200	.0197	.0194	.0192	.0189	.0186	.0184	.0181	.0178
162	.0234	.0230	.0226	.0223	.0219	.0215	.0212	.0209	.0205	.0202	.0199	.0196	.0193	.0191	.0188	.0185	.0183	.0180	.0177
168	.0233	.0229	.0225	.0222	.0218	.0214	.0211	.0207	.0204	.0201	.0198	.0195	.0192	.0190	.0187	.0184	.0182	.0179	.0177
174	.0232	.0228	.0221	.0220	.0217	.0213	.0210	.0206	.0203	.0200	.0197	.0194	.0191	.0189	.0186	.0183	.0181	.0179	.0176
180	.0231	.0227	.0223	.0219	.0216	.0212	.0209	.0205	.0202	.0199	.0196	.0193	.0190	.0188	.0185	.0182	.0180	.0178	.0176

THREE-PHASE values of CHARGING CURRENT at 60 cycles per 1000 volts between two conductors.

TABLE XIII

SOLID CONDUCTORS

Divide values in this table by 100. Amperes each conductor per 1000 feet of conductor (three-phase) formed by 3 parallel bare conductors.

Interaxial Distance, Inches	SIZE OF CONDUCTOR—B.&S. GAUGE																		
	0000	000	00	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
3/8	...	...	...	6.408	1.376	.7890	.5680	.4490	.3750	.3235	.2998	.2565	.2290	.2148	.1995	.1860	.1746	.1642	.1555
1/2	2.295	1.008	.6670	.5036	.4100	.3485	.3045	.2710	.2451	.2243	.2073	.1934	.1777	.1695	.1600	.1515	.1442	.1372	.1315
3/4	.4521	.3762	.3250	.2870	.2574	.2348	.2156	.1995	.1860	.1746	.1646	.1555	.1460	.1407	.1346	.1285	.1233	.1185	.1141
1	.3052	.2741	.2456	.2248	.2072	.1930	.1803	.1694	.1600	.1520	.1442	.1376	.1302	.1258	.1211	.1163	.1120	.1080	.1046
2	.1808	.1698	.1603	.1520	.1446	.1380	.1315	.1263	.1211	.1163	.1124	.1080	.1037	.1010	.0980	.0950	.0923	.0893	.0871
3	.1480	.1411	.1337	.1290	.1237	.1190	.1145	.1102	.1063	.1028	.0997	.0967	.0928	.0906	.0880	.0858	.0836	.0815	.0793
4	.1320	.1263	.1215	.1167	.1124	.1085	.1045	.1010	.0980	.0950	.0924	.0897	.0867	.0845	.0828	.0806	.0784	.0767	.0745
5	.1215	.1167	.1123	.1085	.1050	.1015	.0984	.0954	.0923	.0897	.0871	.0850	.0823	.0806	.0784	.0766	.0750	.0732	.0714
6	.1145	.1102	.1062	.1028	.0997	.0967	.0936	.0906	.0884	.0858	.0836	.0814	.0788	.0775	.0754	.0736	.0723	.0706	.0688
7	.1088	.1054	.1020	.0984	.0954	.0928	.0902	.0876	.0849	.0828	.0806	.0789	.0762	.0750	.0732	.0714	.0702	.0684	.0671
8	.1045	.1010	.0980	.0950	.0923	.0897	.0871	.0850	.0828	.0806	.0784	.0767	.0745	.0732	.0714	.0697	.0684	.0666	.0654
9	.1010	.0980	.0950	.0923	.0897	.0871	.0849	.0828	.0806	.0784	.0766	.0750	.0727	.0714	.0697	.0684	.0666	.0654	.0640
10	.0984	.0954	.0923	.0898	.0876	.0850	.0828	.0806	.0788	.0767	.0749	.0732	.0710	.0697	.0684	.0671	.0654	.0640	.0627
11	.0958	.0928	.0902	.0880	.0854	.0832	.0810	.0788	.0771	.0749	.0736	.0719	.0697	.0684	.0671	.0658	.0645	.0632	.0618
12	.0936	.0910	.0884	.0858	.0836	.0815	.0793	.0775	.0758	.0740	.0723	.0706	.0688	.0675	.0662	.0649	.0636	.0623	.0610
15	.0884	.0862	.0836	.0814	.0797	.0775	.0758	.0740	.0723	.0706	.0692	.0680	.0658	.0649	.0636	.0623	.0610	.0601	.0588
18	.0850	.0828	.0806	.0784	.0767	.0749	.0732	.0714	.0697	.0684	.0666	.0654	.0640	.0627	.0618	.0606	.0592	.0584	.0571
21	.0819	.0797	.0780	.0758	.0741	.0723	.0710	.0693	.0680	.0662	.0649	.0636	.0623	.0614	.0601	.0588	.0580	.0566	.0558
24	.0793	.0775	.0758	.0740	.0723	.0706	.0693	.0675	.0662	.0649	.0636	.0623	.0610	.0601	.0588	.0575	.0566	.0558	.0549
30	.0758	.0740	.0723	.0706	.0692	.0675	.0662	.0649	.0636	.0623	.0610	.0601	.0588	.0580	.0566	.0558	.0549	.0540	.0532
36	.0732	.0714	.0697	.0684	.0666	.0653	.0640	.0627	.0618	.0606	.0592	.0584	.0570	.0562	.0553	.0544	.0532	.0523	.0514
42	.0710	.0693	.0680	.0662	.0649	.0636	.0623	.0614	.0601	.0588	.0580	.0571	.0558	.0549	.0540	.0532	.0523	.0514	.0506
48	.0692	.0675	.0662	.0649	.0636	.0623	.0610	.0601	.0588	.0579	.0566	.0558	.0544	.0536	.0532	.0523	.0514	.0506	.0497
54	.0675	.0662	.0649	.0636	.0623	.0610	.0601	.0588	.0579	.0566	.0558	.0549	.0536	.0527	.0523	.0514	.0506	.0497	.0488
60	.0662	.0649	.0636	.0623	.0610	.0601	.0588	.0579	.0566	.0558	.0549	.0540	.0527	.0523	.0514	.0506	.0497	.0488	.0483
66	.0653	.0640	.0627	.0614	.0601	.0592	.0579	.0571	.0562	.0549	.0540	.0532	.0523	.0514	.0506	.0497	.0492	.0483	.0476
72	.0640	.0627	.0618	.0606	.0592	.0584	.0571	.0562	.0553	.0543	.0534	.0525	.0315	.0509	.0501	.0492	.0485	.0478	.0471
78	.0634	.0621	.0610	.0597	.0586	.0575	.0566	.0555	.0546	.0537	.0528	.0518	.0509	.0503	.0495	.0487	.0481	.0473	.0466
84	.0625	.0613	.0602	.0590	.0579	.0569	.0559	.0550	.0540	.0531	.0522	.0513	.0504	.0497	.0490	.0483	.0476	.0468	.0462
90	.0619	.0606	.0595	.0584	.0573	.0563	.0553	.0544	.0534	.0526	.0517	.0508	.0499	.0493	.0486	.0478	.0472	.0464	.0457
96	.0611	.0600	.0589	.0578	.0568	.0558	.0548	.0539	.0530	.0521	.0512	.0504	.0495	.0489	.0482	.0474	.0468	.0460	.0454
102	.0605	.0594	.0583	.0572	.0562	.0552	.0543	.0533	.0525	.0516	.0508	.0500	.0490	.0485	.0478	.0470	.0464	.0457	.0451
108	.0600	.0588	.0578	.0567	.0557	.0547	.0538	.0529	.0520	.0512	.0504	.0496	.0486	.0481	.0474	.0467	.0460	.0454	.0448
114	.0594	.0583	.0573	.0563	.0552	.0543	.0534	.0525	.0516	.0508	.0501	.0493	.0483	.0478	.0471	.0464	.0457	.0451	.0444
120	.0589	.0578	.0568	.0558	.0549	.0539	.0530	.0521	.0513	.0505	.0497	.0489	.0480	.0475	.0468	.0461	.0455	.0448	.0442
126	.0584	.0574	.0564	.0554	.0544	.0536	.0526	.0518	.0510	.0502	.0494	.0486	.0477	.0472	.0465	.0458	.0452	.0446	.0440
132	.0580	.0570	.0560	.0550	.0541	.0532	.0523	.0514	.0506	.0499	.0490	.0483	.0475	.0469	.0462	.0456	.0449	.0443	.0437
138	.0576	.0566	.0556	.0547	.0537	.0528	.0520	.0512	.0504	.0496	.0488	.0481	.0472	.0467	.0459	.0453	.0446	.0440	.0435
144	.0573	.0562	.0552	.0543	.0534	.0525	.0516	.0509	.0500	.0492	.0485	.0478	.0469	.0464	.0457	.0451	.0444	.0438	.0433
150	.0569	.0559	.0549	.0540	.0530	.0522	.0514	.0505	.0498	.0490	.0482	.0476	.0467	.0462	.0455	.0449	.0442	.0436	.0431
156	.0566	.0556	.0546	.0537	.0528	.0520	.0511	.0503	.0495	.0487	.0480	.0473	.0464	.0460	.0453	.0447	.0440	.0434	.0429
162	.0562	.0553	.0543	.0535	.0525	.0516	.0508	.0500	.0492	.0485	.0478	.0470	.0462	.0458	.0451	.0445	.0438	.0432	.0427
168	.0559	.0550	.0540	.0532	.0523	.0514	.0506	.0498	.0490	.0483	.0476	.0468	.0460	.0456	.0449	.0443	.0436	.0430	.0425
174	.0556	.0547	.0537	.0528	.0520	.0511	.0504	.0496	.0488	.0481	.0474	.0466	.0458	.0453	.0447	.0441	.0434	.0428	.0423
180	.0553	.0544	.0535	.0526	.0517	.0509	.0501	.0493	.0486	.0479	.0472	.0464	.0456	.0451	.0445	.0439	.0433	.0427	.0421

THREE-PHASE values of CHARGING CURRENT at 25 cycles per 1000 volts between two conductors.

TABLE XII

Divide values in this table by 100. Amperes each conductor per 1000 feet of conductor (three-phase) formed by 3 parallel bare conductors.

SOLID CONDUCTORS

Interaxial Distance, Inches	SIZE OF CONDUCTOR—B.&S. GAUGE																		
	0000	000	00	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
3/8	...	...	...	2.670	.5738	.3290	.2366	.1870	.1562	.1348	.1248	.1068	.0955	.0895	.0831	.0775	.0728	.0684	.0648
1/2	.9560	.4200	.2780	.2098	.1707	.1452	.1268	.1128	.1022	.0935	.0864	.0806	.0741	.0706	.0666	.0632	.0601	.0572	.0548
3/4	.1885	.1568	.1353	.1196	.1073	.0978	.0898	.0831	.0775	.0728	.0686	.0648	.0608	.0586	.0561	.0536	.0514	.0494	.0476
1	.1272	.1134	.1023	.0936	.0864	.0804	.0752	.0706	.0667	.0634	.0601	.0574	.0542	.0524	.0504	.0485	.0466	.0450	.0436
2	.0753	.0708	.0668	.0634	.0602	.0575	.0548	.0526	.0504	.0485	.0468	.0450	.0432	.0421	.0408	.0396	.0385	.0372	.0363
3	.0617	.0588	.0557	.0537	.0516	.0495	.0477	.0459	.0443	.0427	.0416	.0403	.0387	.0378	.0367	.0358	.0349	.0339	.0330
4	.0550	.0526	.0506	.0486	.0468	.0452	.0436	.0421	.0408	.0396	.0385	.0374	.0361	.0352	.0345	.0336	.0327	.0319	.0310
5	.0506	.0486	.0468	.0452	.0437	.0423	.0410	.0397	.0385	.0374	.0363	.0354	.0343	.0336	.0327	.0320	.0312	.0305	.0298
6	.0477	.0459	.0443	.0428	.0416	.0403	.0390	.0378	.0368	.0358	.0349	.0340	.0329	.0323	.0314	.0307	.0301	.0294	.0287
7	.0454	.0439	.0425	.0410	.0398	.0387	.0376	.0365	.0354	.0345	.0336	.0329	.0318	.0312	.0303	.0298	.0292	.0285	.0279
8	.0436	.0421	.0408	.0396	.0385	.0374	.0363	.0354	.0345	.0336	.0327	.0320	.0310	.0303	.0298	.0290	.0285	.0278	.0272
9	.0421	.0408	.0396	.0385	.0374	.0363	.0354	.0345	.0336	.0327	.0320	.0312	.0303	.0298	.0290	.0285	.0278	.0272	.0267
10	.0410	.0397	.0385	.0374	.0365	.0354	.0345	.0336	.0329	.0320	.0312	.0305	.0296	.0290	.0285	.0280	.0272	.0267	.0261
11	.0399	.0387	.0376	.0367	.0356	.0347	.0338	.0329	.0321	.0312	.0307	.0300	.0290	.0285	.0280	.0274	.0269	.0263	.0258
12	.0390	.0379	.0368	.0358	.0349	.0340	.0330	.0323	.0316	.0309	.0301	.0294	.0287	.0281	.0276	.0270	.0265	.0260	.0254
15	.0368	.0359	.0349	.0340	.0332	.0323	.0316	.0309	.0301	.0294	.0289	.0283	.0274	.0270	.0265	.0260	.0254	.0250	.0245
18	.0354	.0345	.0336	.0327	.0320	.0312	.0305	.0298	.0290	.0285	.0278	.0272	.0267	.0261	.0258	.0252	.0247	.0243	.0238
21	.0341	.0332	.0325	.0316	.0309	.0301	.0296	.0289	.0283	.0276	.0270	.0265	.0260	.0256	.0250	.0245	.0241	.0236	.0232
24	.0330	.0323	.0316	.0309	.0301	.0294	.0289	.0281	.0276	.0270	.0265	.0260	.0254	.0250	.0245	.0240	.0236	.0232	.0229
30	.0316	.0309	.0301	.0294	.0289	.0281	.0276	.0270	.0265	.0260	.0254	.0250	.0245	.0241	.0236	.0232	.0229	.0225	.0221
36	.0305	.0298	.0290	.0285	.0278	.0272	.0267	.0261	.0258	.0252	.0247	.0243	.0238	.0234	.0231	.0227	.0221	.0218	.0214
42	.0296	.0289	.0283	.0276	.0270	.0265	.0260	.0256	.0251	.0245	.0241	.0238	.0232	.0229	.0225	.0221	.0218	.0214	.0210
48	.0289	.0281	.0276	.0270	.0265	.0260	.0254	.0251	.0245	.0241	.0236	.0232	.0227	.0223	.0221	.0218	.0214	.0210	.0207
54	.0281	.0276	.0270	.0265	.0260	.0254	.0251	.0245	.0241	.0236	.0232	.0229	.0223	.0220	.0218	.0214	.0210	.0207	.0203
60	.0276	.0270	.0265	.0260	.0254	.0251	.0245	.0241	.0236	.0232	.0229	.0225	.0220	.0218	.0214	.0210	.0207	.0203	.0201
66	.0272	.0267	.0261	.0256	.0251	.0247	.0241	.0238	.0234	.0229	.0225	.0221	.0218	.0214	.0210	.0207	.0205	.0201	.0198
72	.0267	.0261	.0258	.0252	.0247	.0243	.0238	.0234	.0230	.0226	.0222	.0219	.0214	.0212	.0209	.0205	.0202	.0198	.0196
78	.0264	.0259	.0254	.0249	.0244	.0240	.0236	.0231	.0228	.0224	.0220	.0216	.0212	.0210	.0206	.0203	.0200	.0197	.0194
84	.0261	.0256	.0251	.0246	.0241	.0237	.0233	.0229	.0225	.0221	.0218	.0214	.0210	.0207	.0204	.0201	.0198	.0195	.0192
90	.0258	.0253	.0248	.0243	.0239	.0234	.0231	.0227	.0223	.0219	.0216	.0212	.0208	.0205	.0202	.0199	.0197	.0193	.0191
96	.0255	.0250	.0245	.0241	.0237	.0232	.0228	.0225	.0221	.0217	.0214	.0210	.0206	.0204	.0200	.0198	.0195	.0192	.0189
102	.0252	.0247	.0243	.0238	.0234	.0230	.0226	.0222	.0219	.0216	.0212	.0208	.0204	.0202	.0199	.0196	.0193	.0191	.0188
108	.0250	.0245	.0241	.0236	.0232	.0228	.0224	.0221	.0217	.0213	.0210	.0207	.0203	.0201	.0198	.0195	.0192	.0189	.0187
114	.0248	.0243	.0239	.0234	.0230	.0226	.0223	.0219	.0215	.0212	.0209	.0205	.0201	.0200	.0196	.0193	.0191	.0188	.0185
120	.0246	.0241	.0237	.0233	.0229	.0225	.0221	.0217	.0214	.0211	.0207	.0204	.0200	.0198	.0195	.0192	.0190	.0187	.0184
126	.0244	.0239	.0235	.0231	.0227	.0223	.0219	.0216	.0212	.0209	.0206	.0203	.0199	.0197	.0194	.0191	.0189	.0186	.0183
132	.0242	.0237	.0233	.0229	.0225	.0221	.0218	.0214	.0211	.0208	.0204	.0202	.0198	.0196	.0193	.0190	.0188	.0185	.0182
138	.0240	.0236	.0232	.0228	.0224	.0220	.0217	.0213	.0210	.0206	.0203	.0200	.0197	.0195	.0192	.0189	.0187	.0184	.0181
144	.0239	.0234	.0230	.0226	.0223	.0219	.0215	.0212	.0208	.0205	.0202	.0199	.0196	.0194	.0191	.0188	.0186	.0183	.0180
150	.0237	.0233	.0229	.0225	.0221	.0218	.0214	.0211	.0207	.0204	.0201	.0198	.0195	.0193	.0190	.0187	.0185	.0182	.0179
156	.0236	.0232	.0227	.0224	.0220	.0216	.0213	.0210	.0206	.0203	.0200	.0197	.0194	.0192	.0189	.0186	.0184	.0181	.0178
162	.0234	.0230	.0226	.0223	.0219	.0215	.0212	.0209	.0205	.0202	.0199	.0196	.0193	.0191	.0188	.0185	.0183	.0180	.0177
168	.0233	.0229	.0225	.0222	.0218	.0214	.0211	.0207	.0204	.0201	.0198	.0195	.0192	.0190	.0187	.0184	.0182	.0179	.0177
174	.0232	.0228	.0224	.0220	.0217	.0213	.0210	.0206	.0203	.0200	.0197	.0194	.0191	.0189	.0186	.0183	.0181	.0179	.0176
180	.0231	.0227	.0223	.0219	.0216	.0212	.0209	.0205	.0202	.0199	.0196	.0193	.0190	.0188	.0185	.0182	.0180	.0178	.0176

TABLE XIII

SOLID CONDUCTORS

THREE-PHASE values of CHARGING CURRENT at 60 cycles per 1000 volts between two conductors.

Divide values in this table by 100. Amperes each conductor per 1000 feet of conductor (three-phase) formed by 3 parallel bare conductors.

Interaxial Distance, Inches	SIZE OF CONDUCTOR—B.&S. GAUGE																		
	0000	000	00	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
3/8	...	...	...	6.408	1.376	.7890	.5680	.4490	.3750	.3235	.2998	.2565	.2290	.2148	.1995	.1860	.1746	.1642	.1555
1/2	2.295	1.008	.6670	.5036	.4100	.3485	.3045	.2710	.2451	.2243	.2073	.1934	.1777	.1695	.1600	.1515	.1442	.1372	.1315
3/4	.4521	.3762	.3250	.2870	.2574	.2348	.2156	.1995	.1860	.1746	.1646	.1555	.1460	.1407	.1346	.1285	.1233	.1185	.1141
1	.3052	.2741	.2456	.2248	.2072	.1930	.1803	.1694	.1600	.1520	.1442	.1376	.1302	.1258	.1211	.1163	.1120	.1080	.1046
2	.1808	.1698	.1603	.1520	.1446	.1380	.1315	.1263	.1211	.1163	.1124	.1080	.1037	.1010	.0980	.0950	.0923	.0893	.0871
3	.1480	.1411	.1337	.1290	.1237	.1190	.1145	.1102	.1063	.1028	.0997	.0967	.0928	.0906	.0880	.0858	.0836	.0815	.0793
4	.1320	.1263	.1215	.1167	.1124	.1085	.1045	.1010	.0980	.0950	.0924	.0897	.0867	.0845	.0828	.0806	.0784	.0767	.0745
5	.1215	.1167	.1123	.1085	.1050	.1015	.0984	.0954	.0923	.0897	.0871	.0850	.0823	.0806	.0784	.0766	.0750	.0732	.0714
6	.1145	.1102	.1062	.1028	.0997	.0967	.0936	.0906	.0884	.0858	.0836	.0814	.0788	.0775	.0754	.0736	.0723	.0706	.0688
7	.1088	.1054	.1020	.0984	.0954	.0928	.0902	.0876	.0849	.0828	.0806	.0789	.0762	.0750	.0732	.0714	.0702	.0684	.0671
8	.1045	.1010	.0980	.0950	.0923	.0897	.0871	.0850	.0828	.0806	.0784	.0767	.0745	.0732	.0714	.0697	.0684	.0666	.0654
9	.1010	.0980	.0950	.0923	.0897	.0871	.0849	.0828	.0806	.0784	.0766	.0750	.0727	.0714	.0697	.0684	.0666	.0654	.0640
10	.0984	.0954	.0923	.0898	.0876	.0850	.0828	.0806	.0788	.0767	.0749	.0732	.0710	.0697	.0684	.0671	.0654	.0640	.0627
11	.0958	.0928	.0902	.0880	.0854	.0832	.0810	.0788	.0771	.0749	.0736	.0719	.0697	.0684	.0671	.0658	.0645	.0632	.0618
12	.0936	.0910	.0884	.0858	.0836	.0815	.0793	.0775	.0758	.0740	.0723	.0706	.0688	.0675	.0662	.0649	.0636	.0623	.0610
15	.0884	.0862	.0836	.0814	.0797	.0775	.0758	.0740	.0723	.0706	.0692	.0680	.0658	.0649	.0636	.0623	.0610	.0601	.0588
18	.0850	.0828	.0806	.0784	.0767	.0749	.0732	.0714	.0697	.0684	.0666	.0654	.0640	.0627	.0618	.0606	.0592	.0584	.0571
21	.0819	.0797	.0780	.0758	.0741	.0723	.0710	.0693	.0680	.0662	.0649	.0636	.0623	.0614	.0601	.0588	.0580	.0566	.0558
24	.0793	.0775	.0758	.0740	.0723	.0706	.0693	.0675	.0662	.0649	.0636	.0623	.0610	.0601	.0588	.0575	.0566	.0558	.0549
30	.0758	.0740	.0723	.0706	.0692	.0675	.0662	.0649	.0636	.0623	.0610	.0601	.0588	.0580	.0566	.0558	.0549	.0540	.0532
36	.0732	.0714	.0697	.0684	.0666	.0653	.0640	.0627	.0618	.0606	.0592	.0584	.0570	.0562	.0553	.0544	.0532	.0523	.0514
42	.0710	.0693	.0680	.0662	.0649	.0636	.0623	.0614	.0601	.0588	.0580	.0571	.0558	.0549	.0540	.0532	.0523	.0514	.0506
48	.0692	.0675	.0662	.0649	.0636	.0623	.0610	.0601	.0588	.0579	.0566	.0558	.0544	.0536	.0532	.0523	.0514	.0506	.0497
54	.0675	.0662	.0649	.0636	.0623	.0610	.0601	.0588	.0579	.0566	.0558	.0549	.0536	.0527	.0523	.0514	.0506	.0497	.0488
60	.0662	.0649	.0636	.0623	.0610	.0601	.0588	.0579	.0566	.0558	.0549	.0540	.0527	.0523	.0514	.0506	.0497	.0488	.0483
66	.0653	.0640	.0627	.0614	.0601	.0592	.0579	.0571	.0562	.0549	.0540	.0532	.0523	.0514	.0506	.0497	.0492	.0483	.0476
72	.0640	.0627	.0618	.0606	.0592	.0584	.0571	.0562	.0553	.0543	.0534	.0525	.0515	.0509	.0501	.0492	.0485	.0478	.0471
78	.0634	.0621	.0610	.0597	.0586	.0575	.0566	.0555	.0546	.0537	.0528	.0518	.0509	.0503	.0495	.0487	.0481	.0473	.0466
84	.0625	.0613	.0602	.0590	.0579	.0569	.0559	.0550	.0540	.0531	.0522	.0513	.0504	.0497	.0490	.0483	.0476	.0468	.0462
90	.0619	.0606	.0595	.0584	.0573	.0563	.0553	.0544	.0534	.0526	.0517	.0508	.0499	.0493	.0486	.0478	.0472	.0464	.0457
96	.0611	.0600	.0589	.0578	.0568	.0558	.0548	.0539	.0530	.0521	.0512	.0504	.0495	.0489	.0482	.0474	.0468	.0460	.0454
102	.0605	.0594	.0583	.0572	.0562	.0552	.0543	.0533	.0525	.0516	.0508	.0500	.0490	.0485	.0478	.0470	.0464	.0457	.0451
108	.0600	.0588	.0578	.0567	.0557	.0547	.0538	.0529	.0520	.0512	.0504	.0496	.0486	.0481	.0474	.0467	.0460	.0454	.0448
114	.0594	.0583	.0573	.0563	.0552	.0543	.0534	.0525	.0516	.0508	.0501	.0493	.0483	.0478	.0471	.0464	.0457	.0451	.0444
120	.0589	.0578	.0568	.0558	.0549	.0539	.0530	.0521	.0513	.0505	.0497	.0489	.0480	.0475	.0468	.0461	.0455	.0448	.0442
126	.0584	.0574	.0564	.0554	.0544	.0536	.0526	.0518	.0510	.0502	.0494	.0486	.0477	.0472	.0465	.0458	.0452	.0446	.0440
132	.0580	.0570	.0560	.0550	.0541	.0532	.0523	.0514	.0506	.0499	.0490	.0483	.0475	.0469	.0462	.0456	.0449	.0443	.0437
138	.0576	.0566	.0556	.0547	.0537	.0528	.0520	.0512	.0504	.0496	.0488	.0481	.0472	.0467	.0459	.0453	.0446	.0440	.0435
144	.0573	.0562	.0552	.0543	.0534	.0525	.0516	.0509	.0500	.0492	.0488	.0478	.0469	.0464	.0457	.0451	.0444	.0488	.0433
150	.0569	.0559	.0549	.0540	.0530	.0522	.0514	.0505	.0498	.0490	.0482	.0476	.0467	.0462	.0455	.0449	.0442	.0436	.0431
156	.0566	.0556	.0546	.0537	.0528	.0520	.0511	.0503	.0495	.0487	.0480	.0473	.0464	.0460	.0453	.0447	.0440	.0434	.0429
162	.0562	.0553	.0543	.0535	.0525	.0516	.0508	.0500	.0492	.0485	.0478	.0470	.0462	.0458	.0451	.0445	.0438	.0432	.0427
168	.0559	.0550	.0540	.0532	.0523	.0514	.0506	.0498	.0490	.0483	.0476	.0468	.0460	.0456	.0449	.0443	.0436	.0430	.0425
174	.0556	.0547	.0537	.0528	.0520	.0511	.0504	.0496	.0488	.0481	.0474	.0466	.0458	.0453	.0447	.0441	.0434	.0428	.0423
180	.0553	.0544	.0535	.0526	.0517	.0509	.0501	.0493	.0486	.0479	.0472	.0464	.0456	.0451	.0445	.0439	.0433	.0427	.0421

TABLE XIV

THREE-PHASE values of CHARGING CURRENT at 100 cycles per 1000 volts between two conductors.

SOLID CONDUCTORS

Divide values in this table by 100. Amperes each conductor per 1000 feet of conductor (three-phase) formed by 3 parallel bare conductors.

Interaxial Distance, Inches	SIZE OF CONDUCTOR—B.&S. GAUGE																		
	0000	000	00	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
3/8	...	...	...	10.680	2.293	1.316	.946	.748	.625	.539	.500	.428	.382	.358	.333	.310	.291	.274	.259
1/2	3.825	1.680	1.112	.839	.683	.581	.507	.452	.409	.374	.346	.322	.296	.282	.266	.253	.240	.229	.219
3/4	.754	.627	.542	.478	.429	.391	.359	.332	.310	.291	.274	.259	.243	.234	.224	.214	.205	.197	.190
1	.509	.454	.410	.575	.346	.322	.301	.282	.267	.253	.240	.229	.217	.210	.202	.194	.187	.180	.174
2	.301	.283	.267	.253	.241	.230	.219	.211	.202	.194	.187	.180	.173	.168	.163	.158	.154	.149	.145
3	.247	.235	.223	.215	.206	.198	.191	.185	.177	.171	.166	.161	.155	.151	.147	.143	.139	.136	.132
4	.220	.211	.203	.195	.187	.181	.174	.168	.163	.158	.154	.150	.144	.141	.138	.134	.131	.128	.124
5	.203	.195	.187	.181	.175	.169	.164	.159	.154	.150	.145	.142	.137	.134	.131	.128	.125	.122	.119
6	.191	.184	.177	.171	.166	.161	.156	.151	.147	.143	.139	.136	.131	.129	.126	.123	.120	.118	.115
7	.181	.176	.170	.164	.159	.155	.150	.146	.142	.138	.134	.131	.127	.125	.122	.119	.117	.114	.112
8	.174	.168	.163	.158	.154	.150	.145	.142	.138	.134	.131	.128	.124	.122	.119	.116	.114	.111	.109
9	.168	.163	.158	.154	.150	.145	.142	.138	.134	.131	.128	.125	.121	.119	.116	.114	.111	.109	.107
10	.164	.159	.154	.150	.146	.142	.138	.134	.131	.128	.125	.122	.118	.116	.114	.112	.109	.107	.105
11	.160	.155	.150	.147	.142	.139	.135	.131	.129	.125	.123	.120	.116	.114	.112	.110	.108	.105	.103
12	.156	.152	.147	.143	.139	.136	.132	.129	.126	.123	.120	.118	.115	.113	.110	.108	.106	.104	.102
15	.147	.144	.139	.136	.133	.129	.126	.123	.120	.118	.115	.113	.110	.108	.106	.104	.102	.100	.0980
18	.142	.138	.134	.131	.128	.125	.122	.119	.116	.114	.111	.109	.107	.105	.103	.101	.0987	.0972	.0950
21	.137	.133	.130	.126	.123	.120	.118	.115	.113	.110	.108	.106	.104	.102	.100	.0980	.0965	.0944	.0929
24	.132	.129	.126	.123	.121	.118	.115	.113	.110	.108	.106	.104	.102	.100	.0980	.0958	.0944	.0930	.0915
30	.126	.123	.120	.118	.115	.113	.110	.108	.106	.104	.102	.100	.0980	.0966	.0944	.0980	.0914	.0900	.0886
36	.122	.119	.116	.114	.111	.109	.107	.105	.103	.101	.0987	.0973	.0951	.0936	.0922	.0908	.0886	.0872	.0856
42	.118	.115	.113	.110	.108	.106	.104	.102	.100	.0980	.0965	.0950	.0929	.0914	.0900	.0886	.0871	.0856	.0842
48	.115	.113	.110	.108	.106	.104	.102	.100	.0980	.0965	.0944	.0929	.0908	.0893	.0886	.0871	.0858	.0842	.0828
54	.113	.110	.108	.106	.104	.102	.100	.0980	.0965	.0944	.0929	.0914	.0893	.0878	.0871	.0856	.0842	.0828	.0813
60	.110	.108	.106	.104	.102	.100	.0980	.0965	.0944	.0922	.0914	.0900	.0878	.0871	.0856	.0842	.0828	.0813	.0806
66	.109	.107	.105	.102	.100	.0987	.0965	.0951	.0936	.0915	.0900	.0886	.0871	.0856	.0842	.0828	.0820	.0806	.0794
72	.107	.105	.103	.101	.0987	.0973	.0951	.0936	.0922	.0904	.0890	.0875	.0658	.0847	.0835	.0820	.0809	.0796	.0784
78	.105	.103	.102	.0996	.0977	.0959	.0942	.0926	.0910	.0894	.0880	.0864	.0848	.0838	.0824	.0812	.0801	.0788	.0777
84	.104	.102	.100	.0984	.0966	.0949	.0932	.0916	.0900	.0854	.0870	.0855	.0540	.0829	.0817	.0804	.0793	.0780	.0770
90	.103	.101	.0992	.0973	.0955	.0938	.0922	.0906	.0890	.0876	.0862	.0848	.0831	.0822	.0810	.0797	.0786	.0773	.0762
96	.102	.100	.0981	.0962	.0946	.0929	.0912	.0898	.0883	.0868	.0854	.0840	.0825	.0314	.0809	.0790	.0779	.0767	.0756
102	.101	.0990	.0972	.0954	.0936	.0920	.0908	.0838	.0875	.0860	.0847	.0834	.0817	.0808	.0796	.0784	.0772	.0762	.0752
108	.100	.0981	.0963	.0945	.0930	.0912	.0896	.0883	.0868	.0854	.0841	.0827	.0811	.0802	.0790	.0779	.0767	.0756	.0746
114	.0900	.0972	.0954	.0938	.0920	.0905	.0890	.0876	.0861	.0847	.0835	.0821	.0806	.0797	.0785	.0773	.0762	.0751	.0740
120	.0981	.0964	.0947	.0930	.0914	.0899	.0834	.0869	.0855	.0842	.0828	.0816	.0800	.0792	.0780	.0768	.0758	.0746	.0737
126	.0974	.0955	.0940	.0923	.0907	.0893	.0877	.0883	.0860	.0836	.0823	.0810	.0795	.0786	.0776	.0764	.0753	.0743	.0732
132	.0967	.0950	.0933	.0916	.0901	.0886	.0871	.0857	.0944	.0831	.0817	.0806	.0791	.0782	.0771	.0760	.0748	.0738	.0728
138	.0960	.0943	.0927	.0912	.0896	.0880	.0866	.0853	.0840	.0825	.0813	.0802	.0786	.0778	.0766	.0755	.0744	.0734	.0724
144	.0954	.0937	.0920	.0908	.0890	.0875	.0861	.0847	.0834	.0820	.0808	.0796	.0782	.0773	.0762	.0751	.0740	.0730	.0721
150	.0947	.0932	.0916	.0900	.0834	.0871	.0856	.0842	.0829	.0817	.0804	.0793	.0778	.0770	.0758	.0748	.0737	.0727	.0717
156	.0942	.0926	.0910	.0894	.0880	.0866	.0852	.0838	.0824	.0812	.0801	.0788	.0774	.0766	.0755	.0744	.0734	.0724	.0714
162	.0936	.0921	.0904	.0892	.0875	.0860	.0847	.0834	.0820	.0808	.0796	.0734	.0770	.0762	.0751	.0740	.0730	.0721	.0712
168	.0932	.0916	.0901	.0886	.0871	.0857	.0848	.0829	.0817	.0804	.0792	.0780	.0766	.0758	.0748	.0738	.0727	.0717	.0708
174	.0927	.0911	.0895	.0880	.0866	.0852	.0839	.0826	.0813	.0801	.0789	.0777	.0763	.0755	.0744	.0734	.0724	.0714	.0706
180	.0922	.0906	.0891	.0876	.0862	.0848	.0835	.0822	.0810	.0798	.0786	.0774	.0760	.0752	.0742	.0731	.0722	.0712	.0703

SELF INDUCTION.

TABLE XV

Millihenries per 1000 feet of conductor (single-phase).

STRANDED CONDUCTORS

Interaxial Distance, Inches	CIRCULAR MILS—SIZE OF CONDUCTOR B.&S. GAUGE													
	500,000	450,000	400,000	350,000	300,000	250,000	0000	000	00	0	1	2	3	4
1	.0758	.0788	.0825	.0835	.0912	.0968	.1017	.1089	.1159	.1229	.1302	.1375	.1444	.1515
2	.1179	.1209	.1246	.1286	.1333	.1389	.1438	.1510	.1580	.1650	.1723	.1796	.1865	.1936
3	.1425	.1455	.1492	.1532	.1579	.1635	.1684	.1756	.1826	.1896	.1969	.2042	.2111	.2182
4	.1601	.1631	.1668	.1708	.1755	.1811	.1860	.1932	.2002	.2072	.2145	.2218	.2287	.2358
5	.1737	.1767	.1804	.1844	.1891	.1947	.1996	.2068	.2138	.2208	.2281	.2354	.2423	.2494
6	.1847	.1877	.1914	.1954	.2001	.2057	.2106	.2178	.2248	.2318	.2391	.2464	.2533	.2604
9	.2094	.2124	.2161	.2201	.2248	.2304	.2353	.2425	.2495	.2565	.2638	.2711	.2780	.2851
12	.2268	.2298	.2335	.2375	.2422	.2478	.2527	.2599	.2669	.2739	.2812	.2885	.2954	.3025
18	.2515	.2545	.2582	.2622	.2669	.2725	.2774	.2846	.2916	.2986	.3059	.3132	.3201	.3272
24	.2690	.2720	.2757	.2797	.2844	.2900	.2949	.3021	.3091	.3161	.3234	.3307	.3376	.3447
30	.2826	.2856	.2893	.2933	.2980	.3036	.3085	.3157	.3227	.3297	.3370	.3443	.3512	.3583
36	.2936	.2966	.3003	.3043	.3090	.3146	.3195	.3267	.3337	.3407	.3480	.3553	.3622	.3693
42	.3031	.3061	.3098	.3138	.3185	.3241	.3290	.3362	.3432	.3502	.3575	.3648	.3717	.3788
48	.3111	.3141	.3178	.3218	.3265	.3321	.3370	.3442	.3512	.3582	.3655	.3728	.3797	.3868
54	.3183	.3213	.3250	.3290	.3337	.3393	.3442	.3514	.3584	.3654	.3727	.3800	.3869	.3940
60	.3247	.3277	.3314	.3354	.3401	.3457	.3506	.3578	.3648	.3718	.3791	.3864	.3933	.4004
72	.3358	.3388	.3425	.3465	.3512	.3568	.3617	.3689	.3759	.3829	.3902	.3975	.4044	.4115
84	.3452	.3482	.3519	.3559	.3606	.3662	.3711	.3783	.3853	.3923	.3996	.4069	.4138	.4209
96	.3533	.3563	.3600	.3645	.3687	.3743	.3792	.3864	.3934	.4004	.4077	.4150	.4219	.4290
108	.3605	.3635	.3672	.3712	.3759	.3815	.3864	.3936	.4005	.4076	.4149	.4222	.4291	.4362
120	.3669	.3699	.3736	.3776	.3823	.3879	.3928	.4000	.4070	.4140	.4213	.4286	.4355	.4426
132	.3726	.3756	.3793	.3833	.3880	.3936	.3985	.4057	.4127	.4197	.4270	.4343	.4412	.4483
144	.3779	.3809	.3846	.3886	.3933	.3989	.4038	.4110	.4180	.4250	.4323	.4396	.4465	.4536
156	.3828	.3858	.3895	.3935	.3982	.4038	.4087	.4159	.4229	.4299	.4372	.4445	.4514	.4585
168	.3873	.3903	.3940	.3980	.4027	.4083	.4132	.4204	.4274	.4344	.4417	.4490	.4559	.4630
180	.3915	.3945	.3982	.4022	.4069	.4125	.4174	.4246	.4316	.4386	.4459	.4532	.4601	.4672

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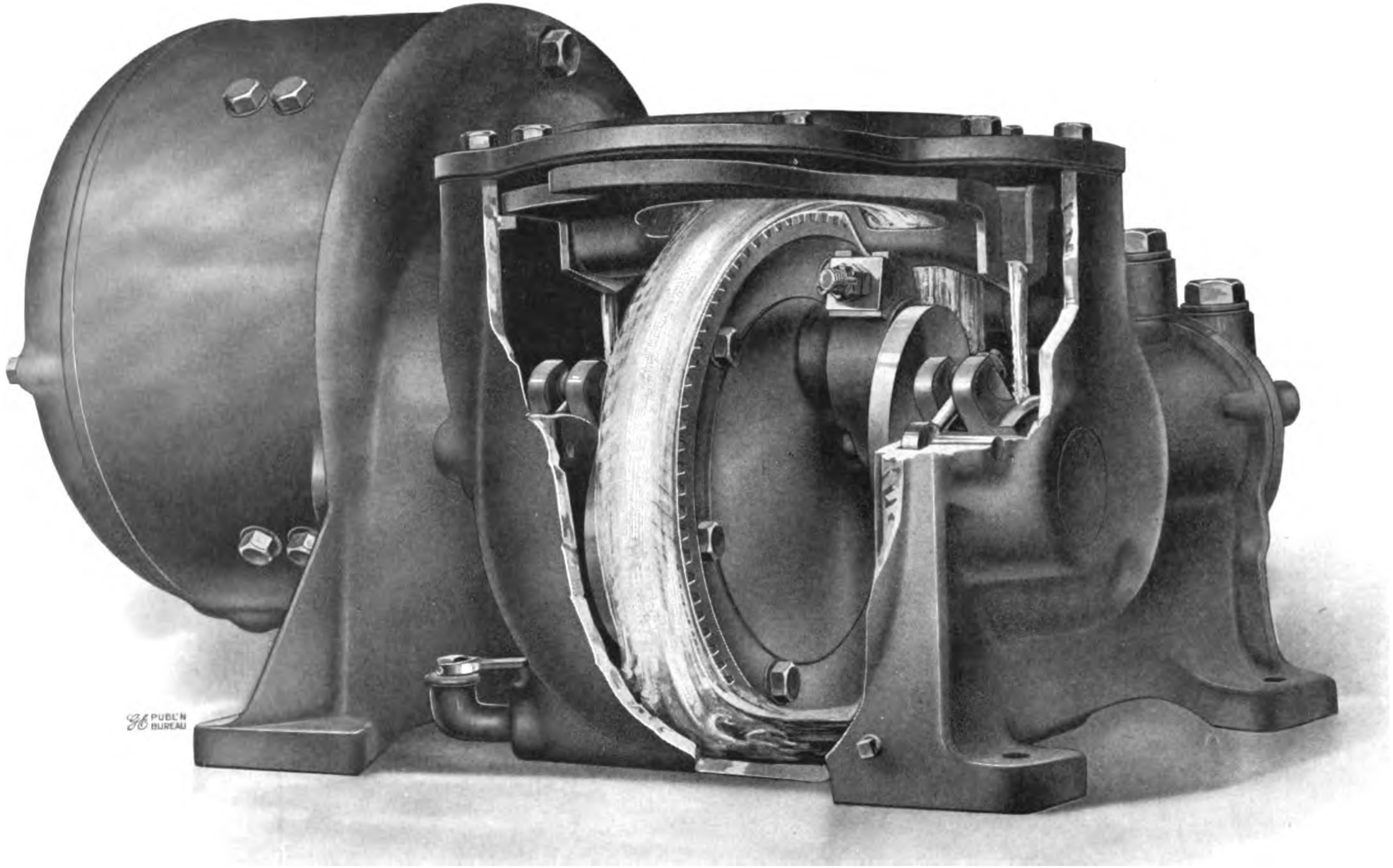
GE PUBL'N BUREAU

Air Compressor for Electric Railway Cars, Showing Method of Lubricating

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GENERAL ELECTRIC
REVIEW

TRANSMISSION LINE CALCULATIONS

The series of articles on transmission line calculations, beginning in this issue of the REVIEW, are intended for a fairly complete, though condensed exposition of the theory and processes involved in designing modern high tension transmission lines. The treatment is sufficiently comprehensive and detailed to enable an electrical engineer to design any line which is likely to be projected in the present stage of development of the art. The tables which have been appearing in the REVIEW for some months are broad enough to include any case which might arise for some time to come.

The time has scarcely arrived for the reduction of transmission line design to a set of rules suitable for application by persons lacking in technical education and training, but the present articles contain nothing which will not be fully available to anyone who is likely to be called upon to design transmission lines. The treatise is accordingly addressed to electrical engineers and professes to be merely a resumé suitable for refreshing the memory and for reference. The synopsis and complete worked example, which will appear in the last numbers of the series, will serve as a key for the solution of any case which might arise and is intended for a working guide.

The articles are printed in two sizes of type. all mathematical demonstrations being in smaller type and the general narrative being in larger type, so that the latter may be read consecutively and the mathematical demonstrations omitted where this may be desirable.

A clear insight into the theory involved is of the greatest importance where departures from conventional design are encountered, and for this reason no use has been made of abridged methods, which, while they slightly lessen the labor involved, completely mask the nature of the operations being performed. The beautiful and classic method of Dr. Steinmetz, based upon the complex variable, has not been used, because, while it is unquestionably the most valuable method of solving alternating current problems, its value is truly appreciated only by those of advanced mathematical attainment, and in the present problems it is by no means always the least laborious method.

MOTOR-DRIVEN AIR COMPRESSORS

With the almost universal adoption of air brakes for electric cars, and a better understanding of their value in reducing the number of accidents and in improving schedule speeds, greater attention is being paid to their selection and purchase, with a view to securing the greatest reliability and the lowest cost of operation and maintenance.

The air compressor is the most important of the component parts of an air brake system, and, as it is usually located where it is subject to the deteriorating action of dirt and water, demands special consideration in order to secure absolute reliability and to eliminate repairs and excessive inspection and maintenance costs. Compressors of the type now in general use, consisting of independent motors and compressors geared together, possess certain objectionable features which are inherent in this general design of machine; such, for example, as noisy operation due to improper alignment of gearing, the necessity of independent lubrication at several different points, the inaccessibility of many parts for inspection, adjustment or repair, and the sacrifice of good electrical characteristics necessitated by the limitations of the motor dimensions.

A new type of motor-driven air compressor is the subject of an article, by Mr. W. E.

Miller, in this issue of the REVIEW. This machine is the first radical improvement that has been made in this class of apparatus since it has come into general use. In this design of machine, the objectionable features that have existed in the types of compressors formerly employed have been eliminated.

PORTABLE SUB-STATIONS FOR ELECTRIC RAILWAYS

In the modern street railway system, where the area to be covered is considerable, it is the general practice to distribute the power in the form of high tension alternating current, transforming it by the aid of step-down transformers and rotary converters to direct current at 600 or 1200 volts for feeding the trolley wire. This transforming apparatus is placed in permanent sub-stations, which are conveniently located for meeting the average demand for current on the different sections or branches of the line.

Now, although these sub-stations may have been carefully designed for normal conditions of service, circumstances are apt to arise which cause certain sections of the line to be overloaded on particular occasions. This is frequently the case with lines serving parks, beaches, gardens, or other summer resorts, where the heavy passenger traffic only lasts for a few weeks during the whole year. Baseball matches, fairs, races, circuses, and crowds on special days often necessitate the employment of a large number of cars on certain portions of the line which usually require but a few cars per day.

Again, in the event of a fire or other accident occurring at a permanent sub-station, an entire section of line may be rendered inoperative, in which case the existence of some substitute of immediate availability is of the utmost importance.

To meet these special conditions, portable sub-stations have been built, consisting of specially arranged cars in which are mounted complete sub-station equipments. These form the subject of the article appearing on page 468 of the present issue.

The use of a portable sub-station for meeting special demands is illustrated in the case of a recently constructed railway system in which the equipment had all been completed with the exception of the high tension transmission lines in one section. A portable sub-station was taken to the furthest point to which the high tension lines had progressed and there connected to the lines. From this sub-station the last section of the railway was successfully operated, whereas, otherwise, it must have remained idle.

In connection with the equipment of portable sub-stations, the employment of steel cars has recently become a prominent feature. These cars are, of course, fireproof, which is an important consideration when the transmission voltage is high; particularly when with a high voltage it is considered desirable, for any reason, to place the lightning arresters in the cars. With the use of steel cars, however, several difficulties arise:

First, on account of the metal's high heat conductivity, the cars tend to be cold in winter and hot in summer; a difficulty met by supplying unusually large ventilating openings designed to keep out driving rain, and fitted with shutters whereby they may be tightly closed in winter. Second, in changeable weather, there is a tendency for moisture to condense upon the roof and sides. Taken in connection with the necessarily close proximity of these surfaces to the high tension lines, this last feature becomes one of serious importance, and special means have therefore been employed to eliminate any possible trouble which might arise from this source. To this end, a galvanized iron lining or ceiling has been placed in such cars and with the framing forms a series of air pockets between itself and the roof. As may be noted in the case of double windows, these pockets of air, acting as heat insulators, form an effective protection against condensation.

Another feature of some interest in these cars is the arrangement of the equipment. One end of the car is devoted exclusively to the high tension apparatus (the incoming lines, oil switches, current transformer, kicking coils, lightning arresters and their disconnecting switches); the other end to low pressure machinery (the rotary converter and low tension switchboard). In the center of the car are placed the transformer, blower and reactive coils, forming a barrier between the two ends.

For this reason, doors have been placed in both ends of the car, as well as in the center. In addition, hinged flaps are provided at the high tension end by means of which the attendant can gain access to the high tension disconnecting switches and open them from the ground with his switch hooks; thereby rendering the entire equipment "dead" before entering the car.

ELECTRIC CRADLE DYNAMOMETER—METHOD FOR TEST OF GASOLINE ENGINES*

By H. S. Baldwin

Historical Sketch

The names of measuring instruments used by scientists and engineers are usually formed by the combination of two Greek words, the first descriptive of what is to be measured, the second indicating the act itself. Thus, thermometer, the measure of heat; tachometer, the measure of speed; dynamometer, the measure of power; and many others. All words of this class are of comparatively recent origin and most of them have been added to our vocabulary within the last century.

In the middle ages religious wars and dissensions did much to postpone the great discoveries in science which have made modern engineering possible. From time immemorial man had used the wind-mill, the water wheel and the horse to aid him in supplying his simple wants, and as sufficient power could be obtained with little effort on his part, he was not particularly interested as to questions of efficiency or economy in the operation of his prime movers. With advanced civilization, however, the problem of existence became more complex, and it was found necessary to have a more reliable source of power than wind or water, also one that could be controlled at will.

Of the three elements of the Ancients, fire, air and water, fire remained, and it was quite correctly reasoned from various phenomena, especially when in contact with water, that heat could be somehow converted into power. If the way to utilize heat could be discovered it was certain that an unlimited supply could be had so long as there was combustible material, and that unlike wind and water it was subject to control. Machines were built for the purpose, but it was many years before the hopes of the early mechanician were realized.

Newcomen was the first to make a really useful steam engine, but its principle and design were crude. It was employed nevertheless to operate slow moving mine pumps.

About 1765 James Watt perfected Newcomen's engine, and in 1769 was granted a patent for the steam engine substantially as we know it to-day.

The foregoing remarks have bearing on the subject of this paper, in that they fix about the time when it was found desirable to have means for measuring power. It was of little consequence to the early miller how much wind or water he used so long as he could grind the grain that was brought to his door. With the advent of the steam engine, however, questions of fuel, water supply, and cost of operation had to be met, and the relation of these to the output of the engine became a matter of great importance. Watt also realized immediately that he must have some standard of power, so that he could rate his engine and give the prospective buyer an idea of how much work it could do. Here he showed good commercial instinct by selecting the power of the horse for a unit. At that time the horse was used for power purposes as well as for traction, and the choice of the term was a happy one, since the customer could readily comprehend it. The question as to what was the real power of a horse then confronted Watt, and as no such unit of measure existed, it became necessary for him to settle this for himself. He therefore made a long series of tests, and as a result determined to his own satisfaction that a work horse could lift a weight of 150 pounds 2½ miles per hour for 10 hours a day, or in other words, perform an amount of work equivalent to lifting 33,000 pounds at a rate of 1 foot per minute. At the time, therefore, when Watt originated the term "horse-power" it undoubtedly conveyed some idea associated with what a horse was capable of doing; now it has lost this significance and has become the recognized unit of mechanical work.

Having adopted a unit of power, Watt found it necessary to prove to the sceptical manufacturer of that day the correctness of his rating. Offhand it would appear that there was little difficulty in this by following the terms of the definition of horse-power to lift a predetermined weight a certain height in a given time. On second thought, however, it is not altogether clear just how this could be done in a satisfactory manner. It would, of course, be necessary to have a clutch of some kind to allow the engine to attain its speed before lifting the weight. Load could only be applied for a short time, otherwise the lifting rope would be wound up on the drum. The difficulties in carrying out this method in practice entirely precluded it.

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* Paper presented before the Society of Automobile Engineers, at Chicago, Ill., Aug. 5, 6 and 7, 1909.

About 1814, Watt devised the steam indicator to record the pressure in the cylinder at all points throughout the stroke and it remains a commentary on his genius that this instrument is today unchanged in principle, although more refined in detail of design. There is no doubt that throughout all his career Watt was a level-headed, practical engineer, and not a dreamer. He overcame every obstacle to the progress of his work. His indicator, however, only permitted the calculation of power developed in the cylinder, and did not give the effective horse-power of the engine.

It is probable that he knew something of the principle of the friction brake, which largely overcame the objection to the cord and drum method already discussed, but if so, no record is found of the fact. He lived between the years of 1736 and 1819, so it is very likely that he was also familiar with the differential transmission dynamometer invented by Samuel White, of England, in 1780, and known in this country by the name of Webber, the inventor who improved its design. This form of dynamometer, perhaps the earliest, although eliminating as it did the serious difficulty of heating met with in the band brake, has never found favor in engine testing, as its construction is too complicated and the fact that gearing is required makes it objectionable for high speed, accurate work.

The absorption or friction dynamometer is generally known in text books and by engineers as the Prony brake, but the fact that G. de Prony was a talented French engineer and writer, who lived from 1755 to 1839, is seldom mentioned. Napolean Bonaparte, 1769–1821, was the patron of inventors and engineers, and employed de Prony on bridge and highway enterprises. The first reference to the Prony brake is in the annals of the Physical and Chemical Society of Paris, in 1821, although it may have been invented at an earlier date.

In the absence of any proof to the contrary, the evidence would indicate that G. de Prony was the inventor of the absorption dynamometer which bears his name, and as such deserves the gratitude of the engineering profession.

Various Forms of Dynamometer

For many years the Prony brake, or its equivalent, the rope brake, afforded the only practical means for obtaining the effective or brake horse-power of steam and gasoline engines. In this form of dynamometer, however, all the power of the engine is absorbed by the friction of a band on a drum located directly at the engine, and the excessive heat generated rendered it difficult to keep the parts cool. Drums, and sometimes bands, were made to contain circulating water, but even with these refinements, anyone who has attempted to hold a given load steadily on a gasoline automobile engine of over 10 horse-power for any length of time, by means of the Prony brake, will appreciate the fact that it cannot be successfully done. With the steam engine or electric motor the same difficulty is experienced, only to a less degree.

The Prony brake represented a step in progress toward a better method for measuring power, and as such, served its purpose well. Many comparatively recent absorption brakes embody the principle of Prony; as for example, the Alden water brake, in which a steel disk is caused to revolve between two copper plates surrounded by water under pressure; the water brake in which a steel disk rapidly revolves in a casing partly filled with water, the skin friction of the disk tending to cause the casing, which is mounted on ball bearings, to revolve; the gear pump in which the pump body is caused to measure torque or pull by throttling a passage between the suction and discharge. All these are designed to give a direct torque reading without the heating caused by rubbing friction in the Prony brake. They are all open to the objection of requiring circulating cooling water, with piping, necessitating a special location and impairing the flexibility of the apparatus. Range of speed control is also limited.

A form of absorption brake which certainly has simplicity and cheapness in its favor is the paddle wheel, working in air, oil or water. This method is only applicable to the commercial test of gasoline engines where it is desired to apply a given load at some fixed speed. In this case the wheel can readily be calibrated by the use of an electric cradle dynamometer hereinafter described.

There is another electrical method which is mentioned only as a matter of interest. It is based on the principle of the damper disk of the electric wattmeter. A large copper wheel is driven by the engine in the field of a powerful electro-magnet, and the disk in cutting the magnetic lines causes eddy currents, tending to retard its rotation.

By mounting the magnet on suitable anti-friction bearings, torque can be measured directly. I do not know that this form of brake has ever been applied to the test of gasoline engines, but it has simplicity in its favor and is the electro-magnetic analogue of the water brake.

Still another method of loading gasoline engines for commercial test is employed by one manufacturer. Engines are belted to a line shaft and their power is utilized to do useful work in driving machinery of the factory. Where large numbers of engines require testing and are being manufactured at a regular and uniform rate, it would appear that this is an economical method of test.

Many manufacturers of gasoline engines for automobiles attach them directly or by means of a flexible coupling to an electric generator of suitable size.

The field of the generator may be separately excited and controlled at will. It is usual in such cases to absorb the output of the generator by means of a water rheostat, although a large cast iron resistance may be used if desired. In order to obtain the brake horse-power of the engine, voltmeter and ammeter readings must be taken. The speed in r.p.m. must also be read from a tachometer. The product of voltage and amperage will give the kilowatt output, and noting that 746 watts represent an electrical horse-power, it is only necessary to divide the output of the generator by its efficiency for the speed at time reading was taken.

It will be seen that this is a somewhat complicated method, owing to the number of readings required, and the large number of variable factors makes it less desirable than the cradle dynamometer method. A correction is frequently necessary for both voltmeter and ammeter, and the brush or bearing friction may change, thereby affecting the efficiency of the generator. Again, results depend largely on the accuracy of the original test from which the characteristic curve was derived. For commercial work the electric generator may be used with reasonably good results, but it is not recommended in the development of new engines or important investigations requiring accuracy.

Commercial test is understood to mean the running of an engine for several hours under constant full load. The electrical energy thus generated may be utilized for factory power or lighting circuits.

So far it has been my object to review briefly the history of the dynamometer in general, and to describe in a few words some of the many forms used for testing gasoline engines. It is not claimed that the list is complete or the discussion exhaustive, for the subject of this paper limits its scope to a description of the cradle dynamometer and what has already been said is only by way of preface to indicate the steps which led up to it.

The Electric Cradle Dynamometer

When the early electric motors were being developed (about 1884-'86,) it is recorded that the cradle dynamometer was devised by Professor Brackett as a more accurate means for ascertaining the "stray power" factors than the Prony brake; and since this form of dynamometer consisted essentially of a cradle upon which was mounted the electric motor to be tested, there can be little doubt as to the approximate date of its origin.

It should be explained that the Brackett dynamometer, while embodying the principle of the modern cradle type, differed in that the motor under test was supported bodily in a frame work which was free to rock through an angle sufficient to permit measurement of pull at the end of an arm. A leather belt was employed to transmit power from the motor pulley to a line shaft. It will readily be seen that this method would be awkward and impracticable for the test of gasoline engines. The principle was correct and the only change necessary was to consider the electric motor as a generator to be used for loading the engine, which is connected to the shaft by means of a flexible coupling rather than by a belt.

In designing electrical apparatus there are many comparatively small factors such as brush friction, bearing friction and windage, I^2R and iron losses, each of which has to be carefully considered in order to obtain machines of high efficiency. All this called for greater refinement in making power measurements than had heretofore obtained, and the cradle dynamometer was found to have the required nicety for the purpose. Manufacturers have continued to use the cradle dynamometer, modified and improved, for so-called "special test" in studying the characteristics of new motors and generators.

It may be asked what are the peculiar advantages of this form of dynamometer?

First. All variable factors are entirely eliminated and it is only necessary to read the pull of the brake arm and note the rotative speed.

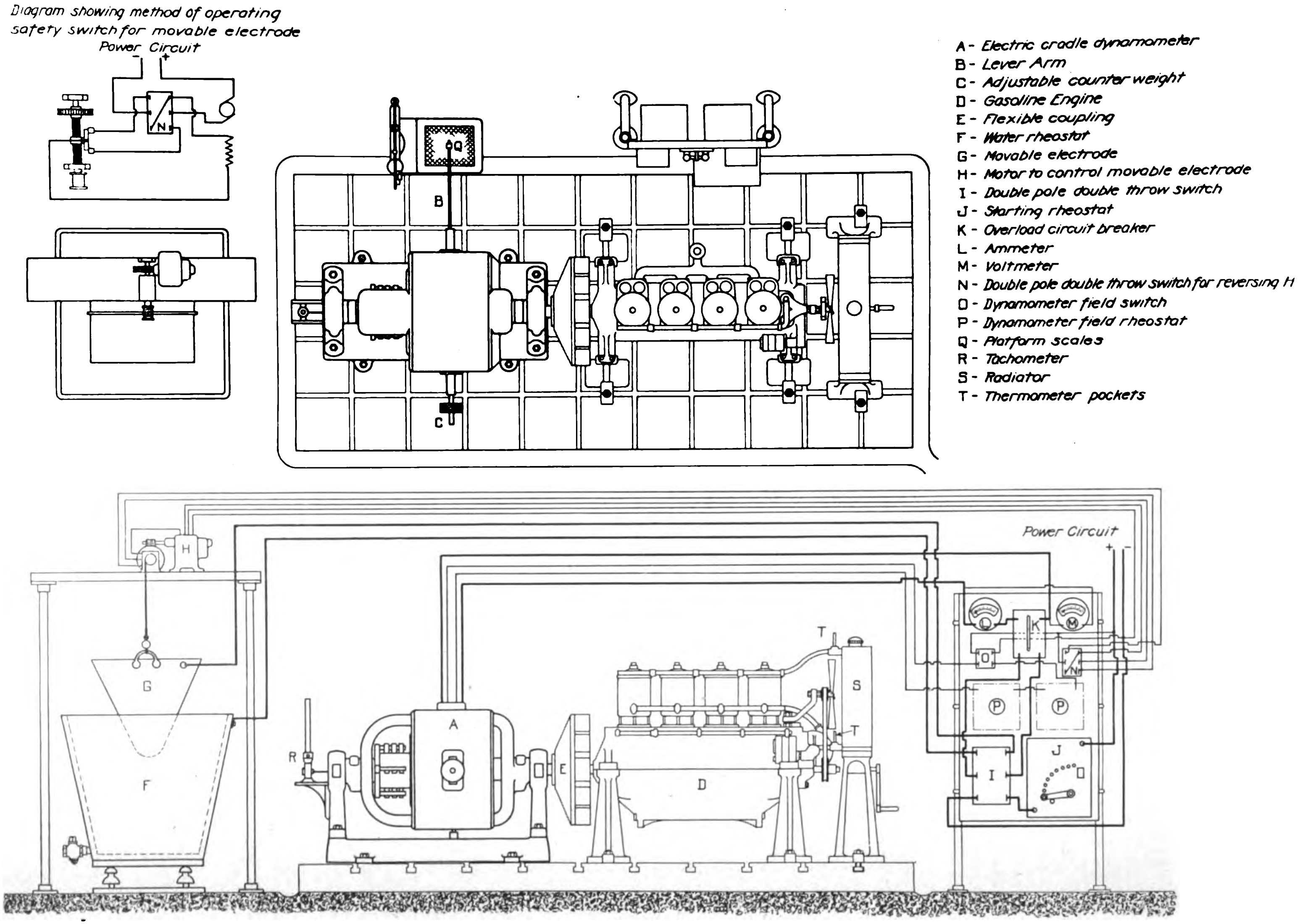
Diagram showing method of operating
safety switch for movable electrode
Power Circuit
- +
N
Q
B
C
A - Electric cradle dynamometer
B - Lever Arm
C - Adjustable counter weight
D - Gasoline Engine
E - Flexible coupling
F - Water rheostat
G - Movable electrode
H - Motor to control movable electrode
I - Double pole double throw switch
J - Starting rheostat
K - Overload circuit breaker
L - Ammeter
M - Voltmeter
N - Double pole double throw switch for reversing H
O - Dynamometer field switch
P - Dynamometer field rheostat
Q - Platform scales
R - Tachometer
S - Radiator
T - Thermometer pockets
Power Circuit
+ -
H
G
F
R
A
E
D
T
S
T
L
K
M
O
N
P
P
I
J

Fig. 1. Suggested Arrangement of Apparatus for Electric Cradle Dynamometer Test of Gasoline Automobile Engine, Including Wiring Diagrams

Second. Load can be held steadily at any desired point within the limits of the dynamometer, for an indefinite time.

Third. This dynamometer is of the absorption type, but the load is dissipated in a suitable rheostat at any desired distance from the dynamometer, which itself only reaches moderate temperature.

Fourth. The cradle dynamometer can be used to measure transmission losses, friction of bearings or other mechanical parts, and the effect of various lubricants.

Fifth. As applied to the test of gasoline engines it may be used for starting the engine.

Some may consider that a well designed water brake has most of the advantages above set forth, but it is certain that the electrical construction presents the greatest possible simplicity. In this, as in all matters, it will undoubtedly be a case of "survival of the fittest."

Commander Krebs, of the Panhard & Levassor Company, appears to have been one of the earliest users of the cradle dynamometer for testing gasoline automobile engines and several members of this society have made use of it for a number of years with success.

The following is a description of a cradle testing outfit laid out by the writer some three and a half years ago (Figs. 1, 2 and 3), for the test of a four-cycle gasoline engine. Excellent records were obtained and a somewhat detailed description may be of interest.

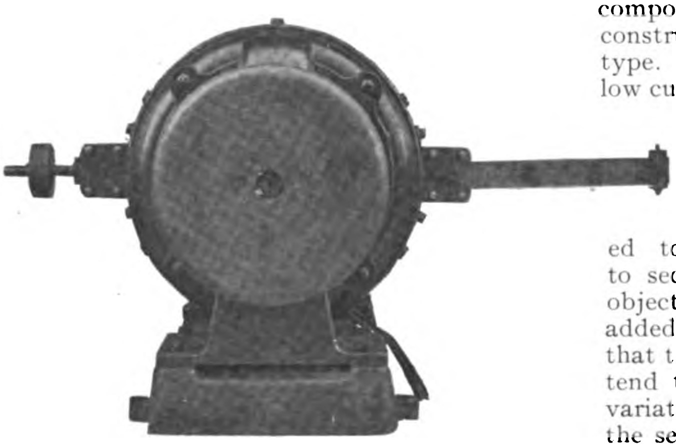

Fig. 3. End View of Dynamometer

So far as ultimate results are concerned, the generator forming the dynamometer may be suitable for any electric circuit, either alternating or direct. It happened that a direct current generator was available, and it was therefore only necessary to choose the type of field winding—series, compound or shunt—and decide whether to use commutating poles or not. The series machine was eliminated owing to the low resistance of its field, requiring high exciting current and consequent loss in cutting down the potential of the line. Again, since it was decided to separately excite the field, there was no particular advantage in the compound winding, and its more complicated construction led to the adoption of the shunt type. Here the field resistance is high with low current, or the reverse of conditions found in the series generator. The question of use of the commutating pole generator was considered, but it was decided that it was not required, since the strength of field could be adjusted to the load and speed of engine so as to secure good commutation. There is no objection to commutating poles, except added first cost, and while experience shows that they are not essential, they undoubtedly tend to better commutation under extreme variation of load. This statement is made, as the service conditions of an engine dynamometer may be severe.

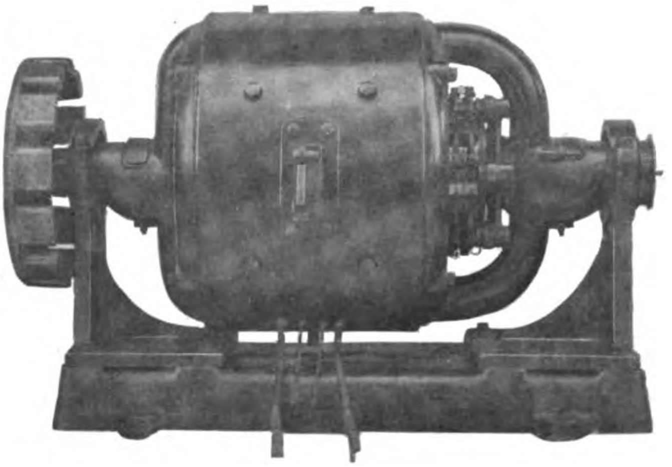

Fig. 2. Side View of Dynamometer

The generator chosen was of 20 horse-power with six poles shunt wound and its successful operation over a period of several years proved the correctness of its selection. No difficulty was found in varying load on engine between

5 and 35 b.h.p., and the latter load could be maintained for two hours or more at rated speed of about 1000 r.p.m. without overheating the dynamometer. For a short period of time it was found that the load could be increased to 40 b.h.p.; also that satisfactory readings could be made at the other extreme of about 5 b.h.p. No attempt was made to reach higher or lower points than these, but if desirable this could undoubtedly be done. Obviously there is no limit to the size of generator and it may be of small capacity for "stray power" readings of electric motors, or of sufficient capacity for the largest gasoline engines. Care must therefore be exercised in the choice of rating of the generator so that it will be suitable for the power range for any particular engine.

The next step was to machine the magnet frame on the outside and adapt the bearing heads to fit large annular ball bearings which would carry the weight of the complete machine with minimum of friction. The frame with field coils in place was then given a rough balancing. A brake arm and stud for counter weight were bolted to the frame diametrically opposite and suitable pedestals were mounted on a base casting so as to receive the ball bearings and support the generator. The counter weight was adjustable radially on the stud, which was threaded.

Most cradle dynamometers that have been called to my attention have had brake arms fitted with weights. This method of measuring the pull has the disadvantage of requiring a number of movable parts or an accurately graduated brake arm. Experience not only in engine testing but in the test of electrical apparatus has shown that best results are obtained by the use of accurate platform or spring scales, thus doing away with the graduation of the dynamometer beam. It is, of course, of great importance that the knife edge of the brake beam be an exact number of feet from the center of the generator shaft, and notches can be cut in the arm at points to give, for example, a length of 2, 3, or 4 feet. Three feet was found to be a convenient length to allow space for the platform scales and passageway for tester. A stop was placed on the magnet frame of the generator to limit its tendency to rotate to a small angle only sufficient to operate scales. This stop is necessary also to prevent reversal of the dynamometer in case the engine should back fire. A bracket was provided on one of the pedestals for a tachometer of the liquid type, which gave good results. A belted mechanical tachometer can be used, but in either case it should be carefully calibrated from time to time to insure accuracy, for it must be understood that the only variable factors in the cradle dynamometer are speed, and weight of pull of brake arm. Of course there is always the personal factor of the observer, but this can be corrected by the employment of a checker on work requiring extreme accuracy. If desired, a continuous record of speed and torque can be obtained by an instrument consisting of a clock-work mechanism actuating a long roll of paper graduated in minutes, on which speed and torque curves are traced in ink by pens. The pens are moved synchronously by two pressure gauges connected by small metal tubes filled with liquid, one to the tachometer on the dynamometer shaft, the other to a small cylinder at the end of the brake arm. When the dynamometer is in operation the pressure in the two columns causes the needles to trace the curves accurately, since liquid is practically non-compressible. In studying the operation of an engine with varying load conditions this method is of value, but for ordinary work at uniform load the simple direct readings are perferable.

It is sometimes said that the only error of the cradle dynamometer is the windage of the armature, but this is only 1 to 2 per cent. of the total output of the generator and can be entirely eliminated by running the armature at the desired speed by means of the gasoline engine and adjusting the counter weight so that the brake arm remains level and the scales read zero.

There are many forms of flexible coupling that may be used between the engine and dynamometer, but there must be real flexibility, otherwise the coupling will cause undue friction by lack of alignment and eventually break. The selection of a good coupling is, therefore, essential, as was found after breaking a number of strong universal joints, and the like. The coupling indicated in the diagram (Fig. 1) was free from objection and in all our tests has stood up well. It is the old interlaced leather belt type, with which all are undoubtedly familiar. It was found desirable to have the larger outer drum mounted on the generator shaft so as not to unduly load the crank shaft of the engine. By so doing, the coupling can be made of comparatively large diameter, facilitating adjustment of leather strap. A locking ring should be provided to hold the belt from slipping out of place and the two drums carefully balanced.

A good way to mount the testing outfit is to use an iron plate divided into squares by T slots near the top surface. The plate should be machined at top, sides and ends and be embedded in concrete. It is desirable to mould a groove or channel in the cement around the plate to catch any oil or water. A base of this kind will greatly facilitate the testing of engines of various sizes and permits of many different combinations and arrangements of apparatus.

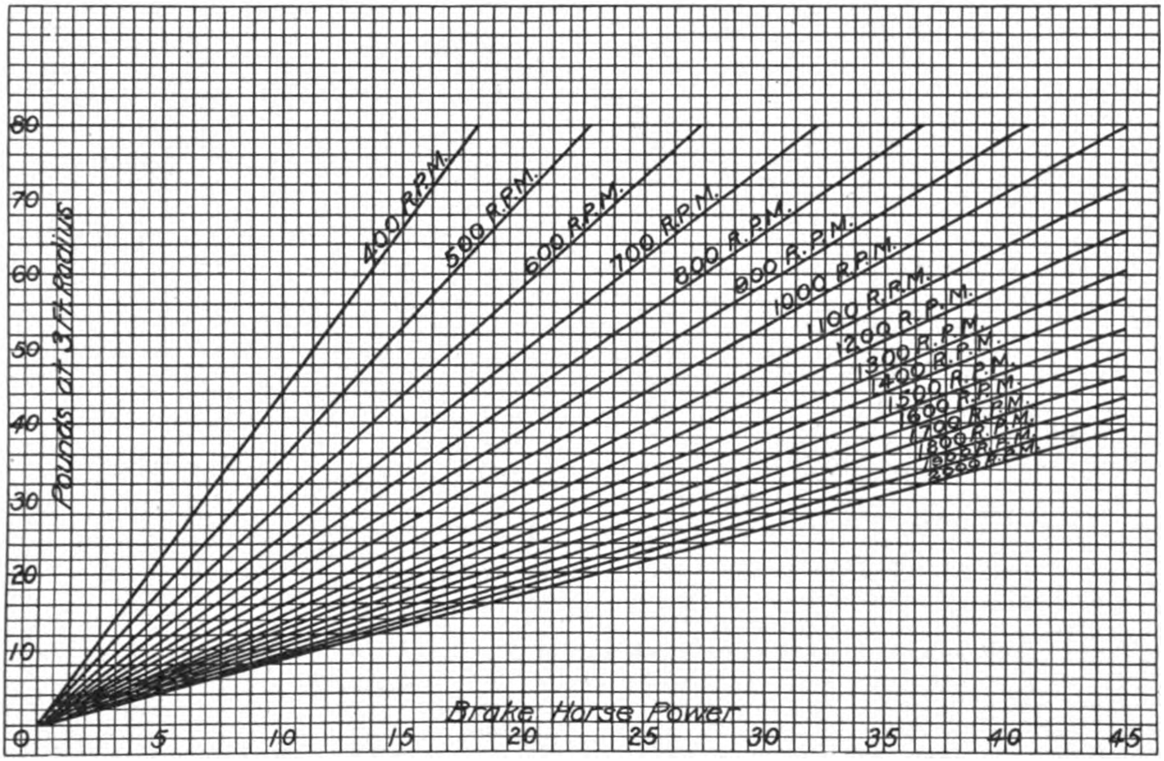

Fig. 4. Curve Showing Brake Horse-Power in Terms of Revs. per Min. and Pull on 3 Ft. Armature

A very convenient and effective form of support for the engine is shown in Fig. 1. Four pedestals are machined on top and bottom to correct height to accommodate the supporting arms of the engine so that the crankshaft shall correctly align with the dynamometer. These are clamped or bolted to the table and the engine set in place. It will readily be seen that this method permits of the greatest possible space under and around the engine and is an improvement on the awkward structures sometimes used.

It is suggested that a test of the engine be made to include one of the radiator as well. From personal experience this is of much interest and value. The radiator should be mounted in correct relation to the engine and fan. If it is desired to make the test more complete, both engine and generator can be covered by a bonnet and air supplied by a large blower in front of the radiator to simulate road conditions. By using this method the water can be kept at any desired temperature at inlet and discharge of radiator. In most cases it is preferable to pipe the engine to a water main or large tank. Care must be taken, however, not to have the water too cold, and to prevent this there should be thermometer pockets at the cylinder inlet and discharge.

There are several ways to dispose of the output of the dynamometer. Some makers recommend that it be used for charging storage batteries; it is usual, however, to consider this energy a loss and dissipate it in a cast iron or water rheostat.

Our experience is favorable to the so-called "water barrel" with movable electrode, and this is the form shown in Fig. 1 at *E*. The receptacle for water is not really a barrel, but a cast iron tank with flaring sides so that ice will not crack it in winter. The electrode *G* is made from a plate of boiler iron and is suspended by a wire cable. It is desirable to insulate the cable from the electrode as shown. The tank is supported on glass insulators, as the circuit is not grounded. A positive wire from the generator should be connected to the movable electrode, as electrolytic action will after a time cause destruction of the plate, which is more cheaply and easily replaced than the tank. A large cock is placed near the bottom to drain off the electrolyte when desired. Clear water is not a good conductor and it is found necessary to add a certain amount of Glauber's salt or sodium sulphate ($Na_2\ So_4$) in order to give the right current capacity. A convenient method is to make a saturated solution of this salt and water in a pail and add as required. This procedure prevents the use of an indefinite amount of salt and will be found to save much time and annoyance. A rheostat as shown in Fig. 1, which is about 3 ft. square on top, can absorb about 25 kw. From time to time it is well to run off the solution and clean out the tank with clear water. A water pipe run to the barrel will save much trouble in filling and cleaning.

In the upper left-hand corner of Fig. 1 is a small diagram. The double throw double-pole switch *N* is the same as is seen on the switchboard and is used for reversing the controller motor *H* which raises and lowers the electrode *G* to regulate load. This is a refinement and is not absolutely necessary, as *G* can be raised and lowered simply by the cord. It often happens, however, that the rheostat cannot be located near the test and it then becomes necessary to find some other means for the purpose. An arrangement to this end has been devised consisting of a small motor which operates a screw by means of a worm and gear having a ratio of reduction of about 1 to 100. There is a safety device so that when the switch is thrown to lift the electrode, for example, the circuit will be opened automatically before any damage is done. Excellent distant control of rheostat is thus obtained without danger of breaking parts or short-circuiting the load line.

It must be understood that the apparatus shown on the switchboard is only for the convenience of the operator, to permit variation of load, to start the engine by using the generator as a motor, and for the protection of the dynamometer itself. In other words, after load is adjusted it is not necessary to have a technical attendant to observe the simple readings which show the brake horse-power of the engine.

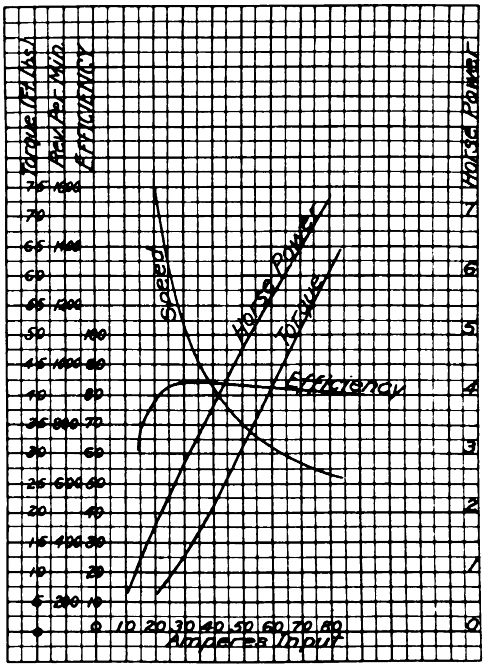

Fig. 5. Typical Characteristic Curve of Electric Automobile Motor

Having the pull of the 3 ft. arm of the dynamometer and the revolutions per minute, the well known Prony brake formula can be applied.

$$Brake\ Horse\text{-}power = \frac{2\pi LPN}{33000}$$

in which L = the length of brake arm in feet; P = the pull at end of arm in pounds, and N = speed of crank shaft in revolutions per minute. Assuming that the arm is to be 3 ft. long the formula becomes

$$B.h.p. = \frac{2 \times \pi \times 3 \times P \times N}{33000}$$

and combining constants.

$B.h.p. = 0.00057 \times P \times N$ which is a simple and sufficiently correct formula for ordinary purposes.

Curve Sheet (Fig. 4) has been prepared to illustrate a short cut for quick horse-power readings without calculation. In this case the brake arm is taken at 3 feet.

Voltages of 115 and 230 direct current have recently been adopted as standard for shop power circuits and the switchboard equipment can be adapted to either.

In order to be able to start the gasoline engine by the dynamometer, the starting box *J*

(Fig. 1) and double-pole double throw switch *I* are wired into the power circuit. If hand-cranking is to be used both starting box and switch can be omitted, much simplifying the board. In either event there should be an adjustable overload circuit breaker *K* to prevent injury to the engine in case of short circuit on the load line.

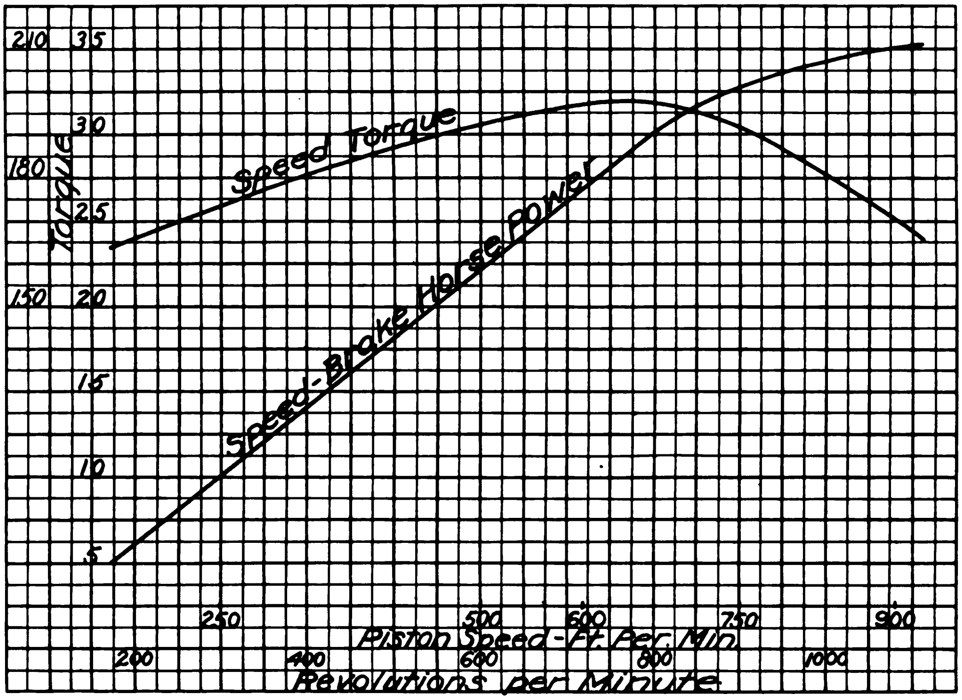

Fig. 6. Actual Characteristic Curve of 4 Cylinder 4 Cycle 5" x 5" Gasoline Automobile Engine

Again, if some part of the engine "seized," preventing it from starting when using the dynamometer as a motor, the circuit breaker would operate and a burnout would be avoided.

The voltmeter *M* and ammeter *L* are not essential but are strongly recommended as indicative of conditions in power and load circuits.

The switch *N* has already been referred to in description of the method for controlling movable electrode. To vary load it is only necessary to momentarily throw reversing switch *N* up or down to raise or lower electrode *G*. If hand control of electrode is preferred, motor *H* and switch *N* can be eliminated. They will, however, be found of great convenience.

It will readily be seen that the switch *O* is in the power circuit of the dynamometer field and should be provided with fuses. The rheostats *PP* afford regulation of field strength, and for fine gradation of load one should have about 10 times the ohmic resistance of the other, with, perhaps, 25 points on each.

In preparing this description of apparatus for the test of gasoline engines it has been the aim of the writer to set forth somewhat in detail such arrangements as have been found, by actual experience, to be useful in studying and improving engines, more particularly with relation to the automobile. Those members who already employ the cradle dynamometer method will undoubtedly be able to add much of value to what has been said, and it is hoped that there will be liberal discussion of the subject which will bring out further points of interest and assistance to the membership in general.

In closing, it is desired to say a few words regarding characteristic curves for gasoline engines. At the meeting in New York a few months ago it was suggested that the society adopt or approve some graphical method to indicate the characteristics of automobile engines, similar in purpose to the speed torque curve of electric motors and generators. Fig. 5 represents a typical curve of a series electric automobile motor, which at a glance enables a purchaser to determine whether or not the particular motor is adapted to his need and if so, to design his transmission mechanism so as to get desired results in speed or current consumption. By means of this curve various traction problems may be solved with reasonable certainty. Why should not similar curves be generally employed by automobile engineers for gasoline engines? Figs. 6 and 7 show characteristic speed torque and speed brake horse-power curves prepared from actual test of a four-cylinder four-cycle and a three-cylinder two-cycle engine respectively. Curves like these can be used to great advantage in comparing the performance of an engine with various arrangement and size of valves, carburettors, and ignition devices. After the engine has been perfected, a final curve will indicate .brake horse-power or torque at various speeds and show whether it is adapted for town car, touring car, racer, or commercial truck.

It may be the time has not yet come for this development, but it is safe to predict that it will not be long before such curves are as universal as in the case of the electric motor.

The speed torque curve of the racing engine should be as nearly flat as possible and hold up for high piston speeds. This will be accomplished by employing large valves and passages.

The speed torque curve of the touring car should droop slightly above normal speed of engine.

The speed torque curve of the conservative town car will be similar to that of the truck, having its highest torque for moderate speed. This amounts to the "stiff series characteristic" of the electric automobile motor and affords great flexibility without frequent change of gear.

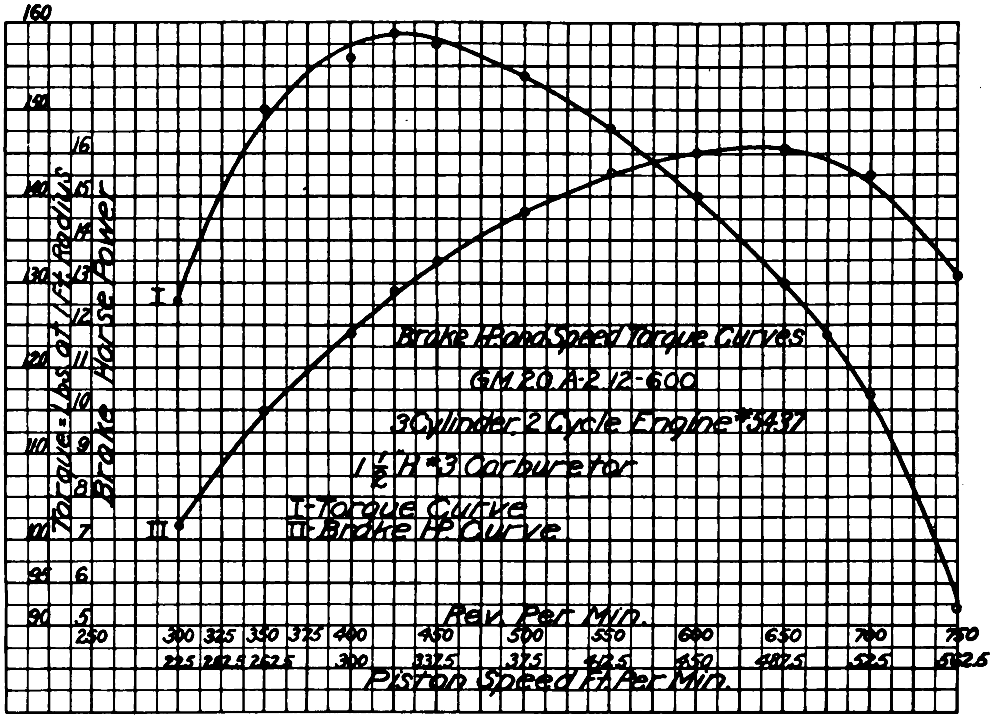

Fig. 7. Actual Characteristic Curve of 3 Cylinder 2 Cycle 4 1/4 x 4 1/2 Gasoline Marine Engine

It will be noted that the brake-horsepower curve continues to rise after the intersection of the two curves, but it is clear that the horsepower thus indicated is obtained by additional piston speed of the engine, and therefore cannot be depended upon except for short periods. In other words, it represents a peak of power which cannot be sustained. The speed torque curve must be looked to for the long pull.

These are only a few of the advantages of characteristic curves, and it is earnestly hoped that some action may be taken by the society to adopt a standard form of curve, either like the ones here shown or adapted from them.

TRANSMISSION LINE CALCULATIONS

PART I

BY M. W. FRANKLIN

Voltage Determination

The voltage selected for a transmission line should be so chosen as to insure the most economical ensemble. Diversely various factors affect the problem and their nature makes the mathematical expression difficult, complicated and unsatisfactory.

The cross-sectional area and, consequently, the weight of conductors varies inversely as the square of the voltage for a given power transmission. The cost of conductors is therefore reduced 75 per cent. each time the voltage is doubled; it would seem proper, therefore, to use the highest voltage possible in any given case. On the other hand, while the cost of the conductors decreases with increasing voltage, the cost of other apparatus and appliances increases. Generators, transformers, insulation and circuit opening and closing devices become expensive when manufactured for very high pressures, if reasonable safety and reliability are to be insured.

With the higher voltages, lightning protection becomes more difficult and expensive; the additional insulation required increases the cost; and the dangerous character of the high potentials necessitates a better and more expensive system of construction and protection.

In the case of the longest lines, from about 100 miles up, the saving in copper with the highest practicable voltages is so great that the increase in other expenses is rendered comparatively insignificant. In the shorter lines, however, ranging in length from about one mile to 60 or 75 miles, the most suitable voltage must be determined in each individual case. Rigid standards cannot be established, though with certain exceptions and modifications, the voltages given in the following table will serve as a guide:

VOLTAGES ADVISABLE FOR VARIOUS LINE LENGTHS

Length of Line	Voltage	
1 mile	500– 1000	volts
1– 2 "	1000– 2300	"
2– 3 "	2300– 6600	"
3– 10 "	6600– 13200	"
10– 15 "	13200– 22000	"
15– 20 "	22000– 44000	"
20– 40 "	44000– 66000	"
40– 60 "	66000– 88000	"
60–100 "	88000–110000	"

Standard machinery is made for 2300, 6600, 13,200, 22,000, 33,000, 44,000, 66,000, 88,000 and 110,000 volts, and standard generators are made for the above voltages up to and including 13,200 volts.

Lines from one mile to about four miles in length can be economically operated at from 2300 to 6600 volts, the practice being to choose the higher standard voltage when the number of miles exceeds that given in the table; *e.g.*, a line of nine miles length should be operated on 13,200 volts. The costs of these standard equipments are such as to make this practice most economical, when copper saving is balanced against increased cost of apparatus.

Power

The amount of power to be transmitted determines, in a measure, the limit of line voltage. If the most economical voltage considered from the point of view of the line alone, is somewhere in excess of 13,200, step up transformers must be employed, since the highest voltage for which standard generators are manufactured is 13,200. In a given case, the saving in conductor by using the higher voltage may be more than offset by the increased cost of transformers, and the question must be determined for each case.

Frequency

So far as the transmission line alone is concerned, the lower frequencies are the more desirable, in that they tend to reduce the inductance drop and charging current. The inductance reactance of the line is $2\pi fL$ and the inductive drop is therefore directly proportional to the frequency. The charging current is $2\pi fCE$, and is, therefore, also directly proportional to the frequency; f being frequency and E line potential. The natural period of a line, with distributed inductance and capacity, is approximately given by:

$$P = \frac{7900}{\sqrt{LC}}$$

where L is the total inductance in millihenries and C the total capacity in microfarads. Consequently some lower odd harmonic of the impressed frequency may be present which corresponds with the natural period of the line. When this obtains, oscillations of dangerous magnitude may occur. Such coincidences are less likely with the lower frequencies than with the higher. The A.I.E.E. recognizes two frequencies as standard, *viz*:—25 and 60; but frequencies of 15 and in some cases 12.5 are being advocated.

Corona Effect

Highly charged conductors, *i.e.*, conductors at a great difference of potential, exhibit a phenomenon which has been named the corona effect. When the potential difference is very great and the interaxial distance small, a continuous passage of energy takes place through the intervening atmosphere, the amount of which may be an appreciable percentage of the power transmitted.

CRITICAL VOLTAGES FOR CORONA EFFECT

Interaxial Distances Inches	B. & S. No. 10 E (eff)	B. & S. No. 4 E (eff)	B. & S. No. 0000 E (eff)	r=0.5 Inches E (eff)	r=1.0 Inch E (eff)
10	23,000	39,000	64,000	115,000	161,000
20	26,500	46,000	78,000	150,000	230,000
40	30,000	53,000	92,000	184,000	300,000
100	34,500	62,000	110,000	230,000	390,000
200	39,000	69,000	124,000	264,000	460,000
1000	46,000	85,000	156,000	345,000	620,000

The corona effect manifests itself as a bluish, luminous envelope, visible at night and audible as a hissing sound.

The loss due to corona effect takes place at a certain voltage which is critical for each line under given atmospheric conditions, and is determined by the radius of conductors and the interaxial spacing.

The following summarizes the results obtained by several investigators:

1. The critical voltage is not constant for a given line but is dependent somewhat upon atmospheric conditions.

2. The critical voltage increases with both the diameter of conductors, and their distance apart.

3. The same general rules apply to stranded conductors as to solid conductors, the actual diameter of the former being considered as the effective diameter of the conductor.

4. The losses due to corona effect increase very rapidly with increase in voltage, after the critical voltage has been reached.

5. The magnitude of the losses as well as the critical voltage is affected by atmospheric conditions, hence they probably vary with the particular locality, and the season of the year. Therefore for a given locality, a voltage which is normally below the critical point may at times be above the critical voltage, depending upon changes in the weather.

6. Such elements as smoke, fog, moisture, or other particles (dust, snow, etc.) floating in the air, increase the losses; rain, however, apparently has no appreciable effect upon the losses. It follows then that in the design of a transmission line, the atmospheric conditions of the particular locality through which the line passes should be considered.

7. The material of the conductors does not appear to affect the losses; the losses being apparently the same for given conditions (same diameter of conductor, and interaxial spacing) for copper as for aluminum.

8. The critical voltage increases with the separation of conductors.

9. The corona effect and losses incident to it are determined by the maximum value of the voltage wave; therefore this factor should be considered in the design of a transmission line, and the ratio of the maximum to mean value of the voltage wave should be known.

10. The wave shape sometimes varies with changes of load, and therefore corona may manifest itself under certain load conditions, while not under others.

The following values of critical voltages (root-mean-square) are calculated from experimental observations, and while probably not rigorously accurate, they will serve as a basis for calculation, until better results can be obtained.

Line Spacing

Line conductors should be so spaced as to lessen the tendency to leakage and to prevent the wires from swinging together or against the towers. With the more modern suspended disc insulators the radius of free movement is increased and special account should, therefore, be taken of spacing, where these insulators are used.

The spacing should be only sufficient for safety, since increased spacing increases the self induction of the line, and while it lessens the capacity, it does so only in a slight degree.

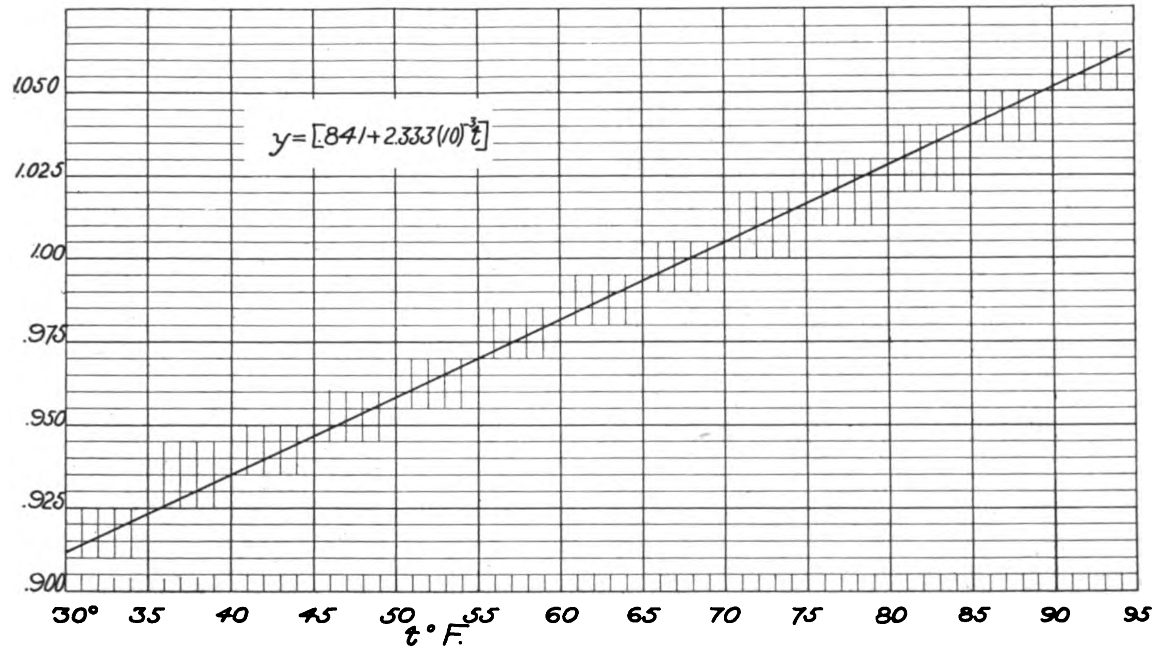

Fig. 1

A wind blowing at right angles to a line deflects equally all wires with the same tension, but when blowing in the direction of the line or at a small angle to this direction, the wires are likely to be set swaying, and may approach each other to within dangerous proximity.

The following spacing is in accordance with average practice:

CONDUCTOR SPACING ADVISABLE FOR VARIOUS VOLTAGES

Volts	Interaxial Distance Inches
5,000	28
15,000	40
30,000	48
45,000	60
60,000	72
75,000	84
90,000	96
105,000	108
120,000	120

Resistance

The resistance of conductors is generally given for certain standard temperatures; *e.g.*, 0° C., 20° C., etc. These resistance values must be corrected for other temperatures.

The following approximate formulæ are given for correcting for temperature. They are correct within the allowable limits of error for many substances, including copper, iron and aluminum.

R_t = resistance at any temperature $t°$ C.
R_0 = resistance at 0° C.
t = any temperature in degrees Centigrade

Then $R_t = R_0(1 + .0042\,t)$ (1)

For Fahrenheit this reduces to

$$R_t = R_m\left[1 + \frac{.0042}{1.8}(t-m)\right] \quad (2)$$

in which R_t = resistance at any temperature Fahrenheit, and R_m = resistance at any given temperature $m°$ Fahrenheit.

Wire resistances are given for 68° Fahrenheit (20° C.) in the tables which follow.

This reduces the formula to

$$R_t = R_{68F}\left[1+\frac{.0042}{1.8}(t-68)\right] \qquad (3)$$

or

$$R_t = R_{68F}\,[.841+2.333\;(10)^{-3}t] = R_{68F}\times y \qquad (4)$$

in which

R_t = resistance at any temperature $t°$ F.

R_{68F} = resistance at 68° F.

t = temperature in degrees F.

$y = [.841+2.333(10)^{-3}t]$

The factors $.841+2.333(10)^{-3}t = y$ may be found from the curve of Fig. 1.

Resistances at temperatures of 68° F. as found in the A.I.E.E. copper wire tables must be multiplied by the factor found in the curve corresponding with the given temperature, to give the resistance at that temperature.

For example:—The average temperature of a given line using No. 0000 solid copper conductors is estimated at 75° F. From the tables the resistance factor (R_{68F}) for a temperature of 68° F. is found to be (.04893) ohms per 1000 feet. The value of y corresponding to 75° F. is found on Fig. 1 to be 1.016.

Hence the resistance of the conductor for 75° F. is $R_{75F} = y \times R_{68F}$ = 1.016 × .04893 = .04971 ohms per 1000 feet.

Approximate Rule for Resistance of Wire

1000 ft. No. 10 B.&S. wire, which is about 1/10 in. in diameter (.1019), has a resistance of one ohm at a temperature of 68° F. and weighs 31.4 pounds. A wire three sizes larger, that is No. 7, has twice the cross section and therefore one half the resistance. A wire three sizes smaller than No. 10, that is No. 13, has one-half the cross section and therefore twice the resistance. Thus, starting with No. 10, any number three sizes larger will double the cross-sectional area and any wire three sizes smaller will halve the cross-sectional area of the preceding wire. This is true to the extreme limits of the table, so that the area, weight and resistance of any wire may be at once calculated to a close approximation from this rule, intermediate sizes being obtained by interpolation.

Accurate Calculation

B.&S. wire gauge numbers are based upon the two fundamental sizes, No. 0000 = 0.46 inch in diameter exactly, and No. 36 = .005 inch diameter exactly.

Any number is derived from the following expression:

$$n = -(9.692 + 19.85 \log d)$$

where n is the B.&S. number.

d is the diameter in inches.

The diameter in inches corresponding to any B.&S. number may be found from the following:

$$d = 0.3249 \times 0.8905^n \text{ or } \log d = \bar{1}.51171 + \bar{1}.94965\,n.$$

The diameters in inches corresponding to the numbers 0, 00, etc. may be calculated from the following:

$d = 0.2893 \times 1.1229^N$, where N = No. of zeros.

……

$$r = 0.09811 \times 1.261^n$$

where r = resistance in ohms per 1000 feet.

$C.M = \dfrac{105{,}500}{1.261^n}$, where $C.M.$ = circular mils.

$W = \dfrac{319.5}{1.261^n}$ for soft copper.

$W = \dfrac{321.7}{1.261^n}$ for hard drawn copper.

where W = pounds per 1000 feet.

Conductors larger than No. 0000 B.&S. are commonly stranded to insure against crystallization, and consequent brittleness, due to repeated bending of a large mass of metal. Also large conductors can be made only in comparatively limited lengths, necessitating frequent and expensive joints; and a considerable deformity results from winding upon reels.

The gauge number of a strand is that of a solid conductor having the same metal cross sectional area.

The weight and resistance of a strand are greater than that of the corresponding solid wire, because the length of each wire is greater than when they are laid straight, and the current tends to follow the axes of the individual wires.

Skin Effect (by W. E. Miller)

For the frequencies and sizes of cables used in transmission lines, skin effect does not appreciably alter the resistance; for example, the resistance of a solid copper wire ¾ in. in diameter at 60 cycles is only increased 2½ per cent., the resistance of a stranded cable of the same external diameter being increased a still smaller amount. The above only refers to non-magnetic materials, but since it is now sometimes the practice to use steel stranded cable for long spans, where skin effect cannot be neglected, the following is given for approximately calculating the increase of resistance, resulting from the surface concentration of current.

In the curve Fig. 2 the ratio of the resistance with skin effect to the resistance with direct current is plotted as ordinates to a quantity called q as abscissæ. The quantity $q = 11.2d\sqrt{\mu k f}$ where d is the external diameter in inches of a solid wire, or in the case of stranded cable, the diameter of the solid wire having the same area, μ is the average permeability, k the specific conductivity (equals $\frac{1}{1600}$ in the case of copper; other materials in proportion) and f the frequency. The conductivity of steel lies between 1/7 to 1/11 that of copper and the permeability between 100 and 400. The value of the permeability which should be chosen, depends on the quality of steel used, and on the reluctance of the magnetic circuit. It therefore decreases with the number of wires used in the cable. It also depends on the concentration of the magnetic flux near the surface of the wire, which depends in turn on the current density in the cable; hence the greater the current (above a certain amount) the smaller the permeability; the value 200 can be generally assumed to be fairly correct.

To calculate the increase of resistance, assume the most probable values for the resistance and permeability of the steel used, and calculate q from the formula, for the given frequency. Opposite to this value of q the increase of resistance is given by the curve. By putting $\mu = 1$, the same process can be used for evaluating the resistance for any non-magnetic substance, but as already stated, the increase of resistance will generally be found so small as to be negligible.

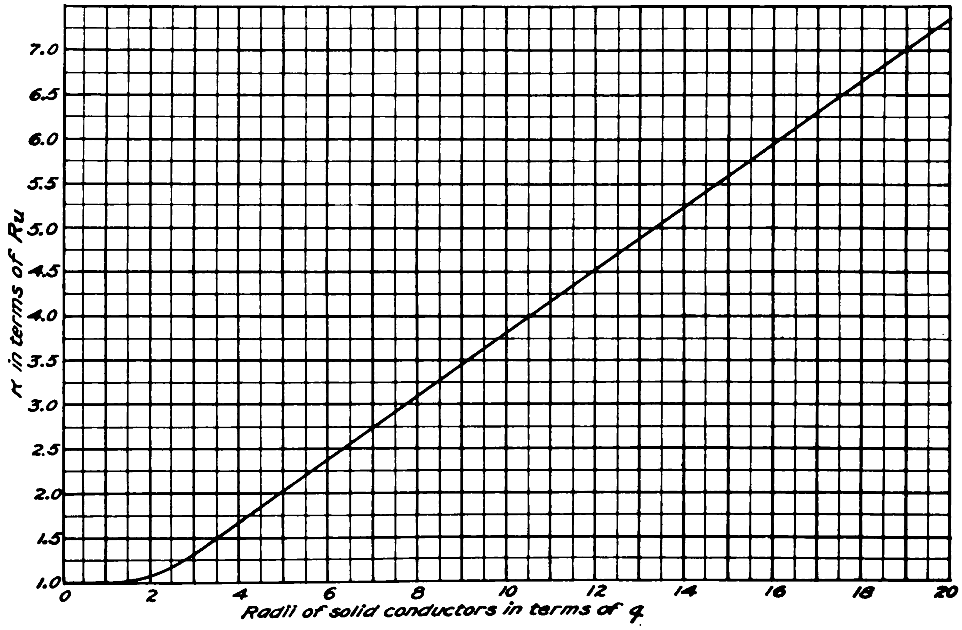

Fig. 2. **Increase of Resistance of Conductors Due to Skin Effect**

For wires or cables of equal conductivity made of non-magnetic substance, skin effect increases the resistance by the same amount; hence, so far as energy loss is concerned, no advantage is gained by using one substance rather than another.

The self induction of a circuit is practically unaltered by the concentration of the current on the surface of the wires or cables, unless the wires lie very close together and the alteration can be neglected in all cases. The effect is to decrease the self induction slightly.

(To be Continued)

LOGARITHMIC CURVES

PART II

BY MAXWELL W. DAY

It will be noted from Fig. 3 * that, should the rate of change be constant at any point, as at A, and continue thus for one second, the increase in value from C to B would be equal to the value of y at A, that is, y would just double itself; but actually, following the curve, y reaches a value of 20.086, thus increasing to a value which is 2.718 times its value at the beginning of the interval.

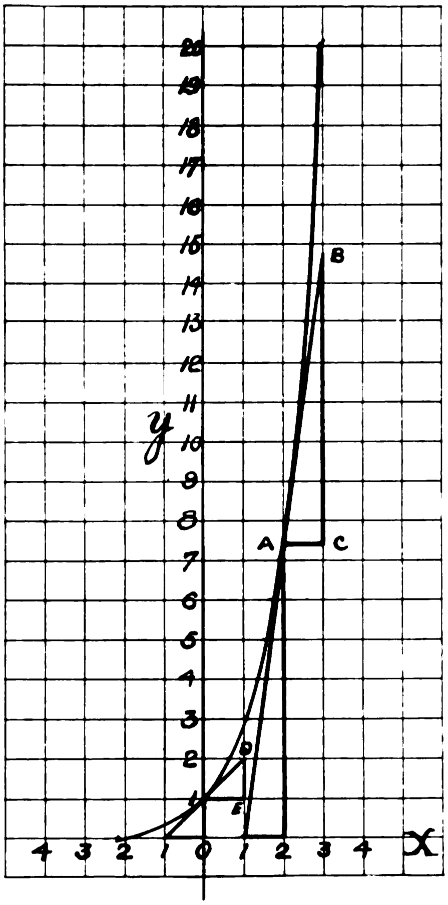

Fig. 3

Thus, similarly, in the small triangle $1DE$, a constant rate of increase would have increased the value of y from 1 to 2, that is, it would have doubled; but actually, following the curve, y increases from 1 to 2.718.

The relation $dy = ydx$ is useful for interpolating between the numbers of the logarithmic tables, without the use of tables of proportional parts.

For example, *ln* 20 = 2.9957; let it be required to find the number whose logarithm is 3. The increment of the logarithm is 0.0043; the increment of the number is almost exactly 20 times 0.0043, or 0.086; and the new number is 20.086.

Given *ln* 53 = 3.9703, to find *ln* 53.4.

As the number increases at a rate equal to the product of its own value, multiplied by the rate at which the logarithm increases (6 ε $dy = ydx$), it will increase almost exactly 53.2 times as fast as the logarithm, between 53 and 53.4. Its own increase is 0.4, hence the increase of the logarithm is 0.4 ÷ 53.2 = 0.00752, and *ln* 53.4 = 3.9703 + 0.0075 = 3.9778.

What has been said before relates to a function which is increasing at a rate *equal* to the value of the function itself at any instant, but in most investigations the rate of increase is not equal to the value of the function but is proportional to that value. If a function increases at a rate greater than that for which the standard time-table is made out, it will reach a given value in less time than that given by the standard table; or it will reach a greater value in the given time. If the rate of increase be twice that of the standard table, the function will reach a given value in one-half the time of the time-table; but it does not follow that it will only reach twice the value in the time of the table, because the velocity is continually increasing.

When the rate of increase of a function is equal to twice the value of the function at any time, the differential equation is expressed $\frac{dy}{dx} = 2\,y$, or $\tan a = 2y$; *i.e.*, the rate of increase is equal to $2y$, and if the rate of increase at any point were made constant, the value of the function would increase by an amount equal to itself in one-half a second, instead of requiring one second; the modulus is therefore ½.

If the function were increasing only one-half as fast as the standard rate, then $\frac{dy}{dx} = \frac{y}{2}$, or $\tan a = \frac{y}{2}$. This means that if the rate of change at any point were made constant it would take two seconds for y to increase by an amount equal to itself, and in this case the modulus would be 2. The equation of the curve corresponding to $\frac{dy}{dx} = 2y$ is $y = \varepsilon^{2x}$, or $x = \frac{1}{2} ln\ y$; and for $\frac{dy}{dx} = \frac{y}{2}$, $y = \varepsilon^{\frac{x}{2}}$, or $x = 2 ln\ y$. The first of these may be expressed as $y = (\varepsilon^2)^x$ and the second as $y = \sqrt{\varepsilon^x}$, or $\sqrt{\varepsilon}^x$, that is, the laws of increase of these functions may be considered as geometrical progressions, one of which has a ratio equal to 2.718^2 and the other equal to $\sqrt{2.718}$. To treat these functions in this manner, however, would involve the use of an excessively large number of tables in working out the time required by the function to change from one value to another, and it is more convenient to use the standard time-table and multiply by the modulus.

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* Fig. 3 as shown on page 406 of the September REVIEW was incorrectly reproduced; the corrected figure is given above, showing more plainly the triangles mentioned

The use of one standard time-table for all of these functions, and the employment of different moduli (as above described) might be compared to using a railway time-table in which are given the times for the various stations for a train running at a mile a minute; and in which instead of the time for each train the time per mile is given. Then the time interval between any two stations for any particular train would be obtained by multiplying the standard interval by the time per mile of that particular train. Similarly, the table of natural logarithms gives the time interval for a function changing at a rate equal to itself, and the time required for any other function is obtained by multiplying this interval by its modulus. This explains why in mathematical investigations involving the use of exponential or logarithmic functions the result is obtained in natural logarithms, the modulus of which is unity.

In the case of bodies moving with constant velocities, one which moves twice as fast as another will cover the same distance in one-half the time, or twice the distance in the same time; but where the velocity of both are changing this relation does not hold true. In the case of a body whose velocity is increasing at a constant rate, such as a body falling to earth, four times the distance will be covered in two seconds that is covered in one; another body accelerating twice as fast will travel twice as far in the same length of time, or $2y$, but will not travel the same distance in one-half the time, requiring instead $\sqrt{\frac{1}{2}} = 0.707$ as much time, or $\frac{x}{\sqrt{2}}$. On the other hand, in the case of two logarithmic curves, if the function of the first increases twice as fast as that of the second, it will attain the same value in one half the time taken by the latter. If both are continued for the same length of time, the first, instead of reaching a value twice as great as the second (that is $2\ y$), will reach a value equal to the square of the second (that is y^2). In one case $y = \varepsilon^x$ and in the other case $z = \varepsilon^{2x}$; when $x = 1$, y is equal to 2.718 and z is equal to $2.718^2 = y^2$. In two seconds $y = 2.718^2$ and $z = 2.718^4$, which again is equal to y^2.

Again in the case of constant acceleration, when one body accelerates three times as rapidly as the other, $y = \frac{1}{2}ax^2$

$$z = \tfrac{1}{2}a_2 x_2^2 = 1\tfrac{1}{2}ax_2^2.$$

and for equal time, $x = x_2$

$$\frac{z}{y} = \frac{1\frac{1}{2}ax^2}{\frac{1}{2}ax^2} = 3$$

$$z = 3y$$

and the distance traveled by one is three times that traveled by the other.

For the same distance $y = z$, and

$$\tfrac{1}{2}ax^2 = 1\tfrac{1}{2}ax_2^2$$

$$x_2^2 = \frac{x^2}{3}$$

$x_2 = \frac{x}{\sqrt{3}}$; and the time required by one, instead of being $\frac{1}{3}$ of the time of the other, is $\sqrt{\frac{1}{3}}$ of that time.

If the rate of increase of the logarithmic function in one case be 2.303 times that of the other, the value reached by z will equal $y^{2\cdot 303}$ for the same interval of time from the time when y and z each equals 1; or the time required to reach the same value will be $\frac{1}{2.303}$, or 0.434 times as much.

$$\frac{dz}{dx} = 2.303\ z$$

$$z = \varepsilon^{2\cdot 303x} = (2.718^{2\cdot 303})^x = 10^x$$

$$x = 0.434\ ln\ z = log\ z$$

In this case $z = 10^x$ and x becomes the logarithm to the base 10 or z; a table of these values constitutes the common or Briggs logarithms. The modulus of this system is 0.434, and the Briggs logarithms can be obtained by multiplying the natural logarithms by 0.434, or the natural logarithms by multiplying the Briggs logarithms by 2.303. These numbers are approximate; for very accurate work more decimals should be used. In the development of logarithmic equations, it is convenient in many cases to develop the equation for Briggs logarithms on account of the greater convenience of these tables.

Fig. 4 represents three logarithmic curves, the equations of which are as follows:

A	$y = \varepsilon^{2.303x}$	$x = 0.434\ ln\ y$
B	$y = \varepsilon^{x}$	$x = ln\ y$
C	$y = \varepsilon^{\frac{x}{2}}$	$x = 2\ ln\ y$

The general expression for any one of these is:

$$y = \varepsilon^{\frac{x}{m}}$$

$$x = m\ ln\ y$$

$$\frac{dy}{dx} = \frac{y}{m}$$

Draw tangents and vertical lines downward from the three curves at the points A, B, C. At some point draw DE parallel to the axis of abscissæ so that DE is equal to 1; then, as explained on page 407, of the September Review, $CE = \frac{dy}{dx}$, which is also equal to $\frac{y}{m}$. OF is the subtangent to the point C and from the similarity of triangles,

$$DE : CE :: OF : CF$$

$$1 : \tfrac{y}{m} :: OF : y$$

$$OF = m$$

That is, the subtangent of a logarithmic curve is constant and equal to the modulus.

If these three tangents be drawn from the points where

$$y = \varepsilon = 2.718$$

the tangents will pass through the origin, because in each case

$$x = m\ ln\ y$$

and as $ln\ y$ equals 1 when y equals ε, $x = m$;

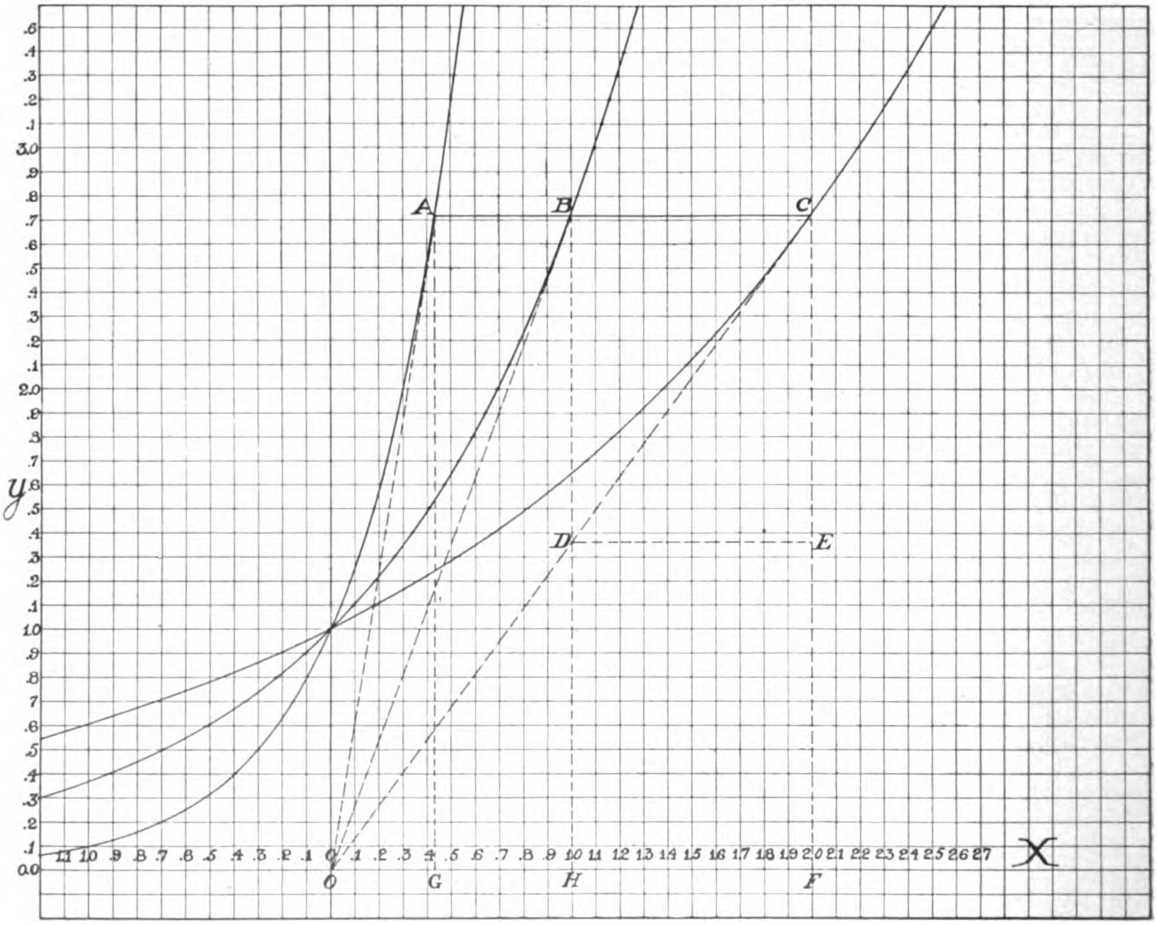


Fig. 4

and OG, the base of the triangle OAG, is equal to the modulus of curve A. OH, the base of the triangle OBH, is equal to the modulus of the curve B, and OF to the modulus of the curve C. As these equal the corresponding values of x and m, the point O must be at the origin.

A tangent drawn to any logarithmic curve at the point where y is equal to the modulus, makes an angle of 45° with the axis of abscissæ. In the differential equation $\frac{dy}{dx} = \frac{y}{m}$, when y is equal to m, $\frac{dy}{dx} = 1$, which is the tangent of the angle of 45°. Hence it follows that in any system of logarithms, when the number is equal to the modulus, the logarithm increases at the same rate as the number; where the number is less than the modulus, the logarithm increases more rapidly, and where the number is greater than the modulus, the logarithm increases more slowly than the number.

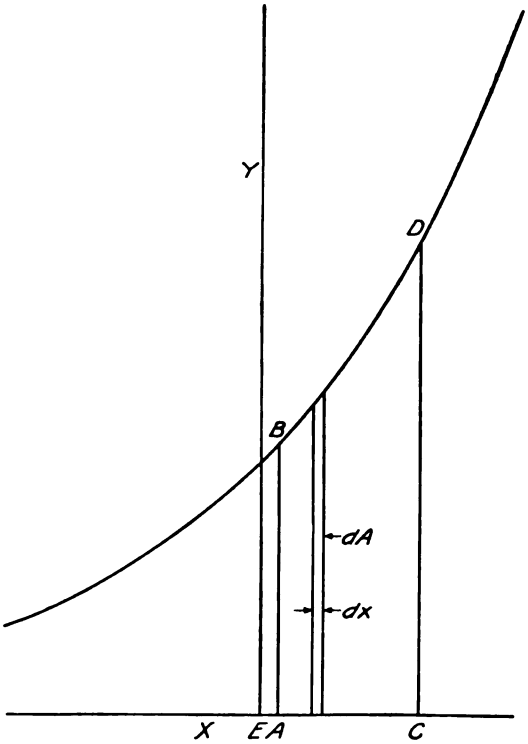


Fig. 5

In the previous discussion the starting point for x has been taken at the ordinate where $y = 1$, and the elapsed time between two values of y is equal to the algebraic difference of the corresponding values of x; when one value of y is less than unity, and the other value is greater than unity, the algebraic difference equals the *numerical* sum, not *algebraic* sum, as stated on page 407 of the last REVIEW.

Although the complete curve extends to infinity in both directions, and the end can not therefore be used as a starting point for x, generally only a portion of the curve is under consideration, and a definite starting point can be found, usually different from the point where the ordinate $y = 1$, and this leads to a general equation different from that previously mentioned.

In Fig. 5 a curve is shown having the equation $y = \varepsilon^{\frac{x}{m}}$ or $x = m\, ln\, y$. The time of B is $m\, ln\, B = E\,A$; and the time of D is $m\, ln\, D = E\,C$; the time between B and D equals $E\,C - E\,A = A\,C$.

Let $t =$ the elapsed time, beginning at A; then when $t = 0$ $\quad x = E\,A$

$t = A\,C \quad x = E\,A + A\,C$

and all cases $x = t + E\,A$. $E\,A$ is a constant and the equation $y = \varepsilon^{\frac{x}{m}}$ becomes $y = \varepsilon^{\frac{t+EA}{m}}$, and $x = m\, ln\, y$ becomes $t = m\, ln\, y - E\,A$.

$$\frac{dy}{dx} = \frac{y}{m}$$

Using the letter x to represent the value of the time measured from the assumed starting point, the equations of the logarithmic curve are:

$$y = \varepsilon^{\frac{x+C}{m}} \quad \text{where } C = EA = \text{constant}.$$

$$x = m\, ln\, y - C$$

$$\frac{dy}{dx} = \frac{y}{m}.$$

It should be noted that the constant C is equal to m times the logarithm of the initial value of y, and where the initial value of y is less than unity, C is negative.

In some cases, such as the current of a shunt wound hoist motor, y is composed of two parts, one of which is constant and the other is a logarithmic function; then instead

of $\quad y = \varepsilon^x$

and $x = ln\, y$

we have $y = \varepsilon^x + k$

$x = ln\ (y - k)$ where $k =$ a constant.

Applying this constant to the equations of the preceding paragraph gives us, as the general equations of logarithmic functions in which both x and y contain constant quantities,

$$y = \varepsilon^{\frac{x+C}{m}} + k$$

$$x = m\, ln\, (y-k) - C$$

$$\frac{dy}{dx} = \frac{y-k}{m}$$

In some cases the equation contains a negative exponent or logarithm, such as $y = \varepsilon^{-\frac{x}{m}}$ or $x = -m\, ln\, y$. In this case $y = \frac{1}{\varepsilon^{\frac{x}{m}}}$ and the curve may be plotted by obtaining m times the natural logarithm of y and plotting it as x on the opposite side of the prime ordinate; that is, positive values are plotted on the left and negative on the right.

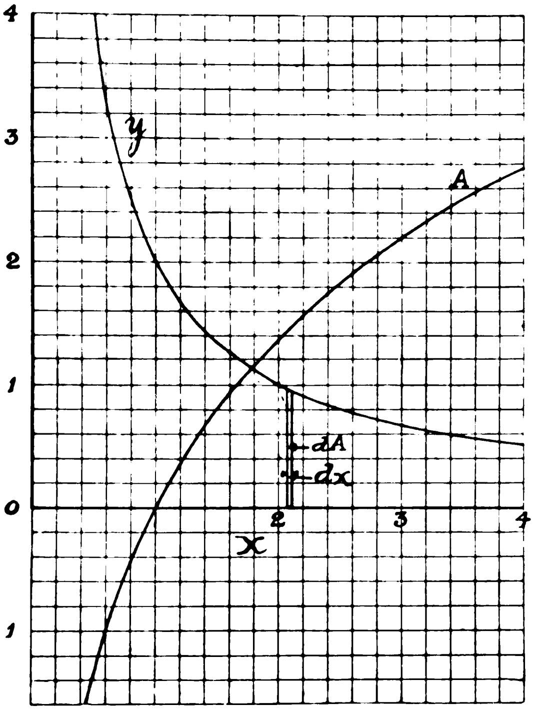


Fig. 6

This gives a curve which decreases from left to right and applies particularly to the discharge current of an electromagnet.

The area included between a logarithmic curve, the axis of abscissæ, and two ordinates is determined as follows:

In Fig. 5, dA represents the infinitesimal increment of the area under the curve corresponding to an infinitesimal increase of x. Its width is dx and its height is y.

$$dA = ydx \qquad A = \int ydx$$

It has already been shown (page 407 of last REVIEW) that

$$ydx = dy, \text{ hence}$$
$$dA = dy$$
$$A = y$$

or the area under the curve between its limit, where $x = -\infty$ and any ordinate, is equal to the value of that ordinate, and consequently the area under the curve between two ordinates is equal to the difference of the ordinates. This applies only to the equation $y = \varepsilon^x$, or $x = ln\, y$.

When $y = \varepsilon^{\frac{x}{m}}$, or $x = m\, ln\, y$

$$\frac{dy}{dx} = \frac{y}{m}$$
$$ydx = mdy$$
$$dA = ydx = mdy$$
$$A = my$$

The area under the curve, between the limit where $x = -\infty$ and any ordinate, is equal to that ordinate multiplied by the modulus; and the area below the curve, between two ordinates, is equal to the difference of the ordinates multiplied by the modulus.

In the equation $y = \varepsilon^x$, the modulus is one; hence, the general rule applies to this case also.

The area under a hyperbola with rectangular co-ordinates may be expressed as a logarithmic function.

Fig. 6 shows a hyperbola of the form $y = \frac{p}{x}$

The infinitesimal increment of the area under the curve is ydx and

$$dA = ydx$$
$$y = \frac{p}{x}$$
$$dA = \frac{pdx}{x}$$
$$A = p \int \frac{dx}{x} = p\, ln\, x$$

When $x = 1$

$$ln\, x = 0$$

and $A = 0$;

so that a starting point for measuring area is the ordinate 1. The area below the curve included between the ordinate where $x = 1$ and any other ordinate, is equal to p times the logarithm of x corresponding to that ordinate. Where the area is measured between ordinates on both sides of the ordinate where $x = 1$, it is equal to the numerical sum or algebraic difference of the areas on each side of the ordinate where $x=1$. The curve in Fig. 6 is plotted to represent the equation $y=\frac{2}{x}$, and the value of the curve A at any ordinate shows the area included under the curve y between that ordinate and the ordinate where $x=1$. It should be noted that this curve crosses the axis of abscissæ where $x=1$.

On account of this relation of area and abscissæ, the natural logarithms are sometimes called *hyperbolic* logarithms.

In conclusion, the following are the principal points to be noted in connection with natural logarithms:

1. ϵ has a geometrical significance as definite as that of π, and is the ratio of increase of a function in a unit of time, the function continually increasing at a rate equal to itself.
2. A table of natural logarithms is a time-table for such a function.
3. Such a time-table may be employed for measuring the time of a function changing at a rate *proportional* to itself by using a multiplying factor or modulus.
4. The difference of time between any two values of y is equal to the time interval of their ratio measured from unity.
5. The common or Briggs logarithms are readily converted into natural logarithms by multiplying by 2.303 (approximately).
6. Abbreviation for natural logarithms is *ln*, and for the Briggs logarithms *log*.
7. A tangent to the curve at any point makes an angle with the axis of abscissæ, the tangent of which is equal to $\frac{y}{m}$.
8. The subtangent at any point is equal to m.
9. The tangent to any logarithmic curve at the point where $y=\epsilon$, passes through the origin.
10. The tangent to any logarithmic curve at the point where $y=m$ makes an angle of 45° with the axis of abscissæ.
11. The area between the curve, the axis of abscissæ, and two ordinates, equals the difference of the ordinates multiplied by the modulus.
12. With a hyperbola having rectangular co-ordinates, the area under the hyperbola and between two ordinates, is equal to the algebraic difference of the logarithms of the corresponding abscissæ multiplied by the parameter of the hyperbola, which is also the modulus of the logarithmic curve of the areas.

RAILWAY CONVERTER POWER FACTOR

By J. E. Woodbridge

Compound wound converters inherently depend upon a variation of power factor for regulation. With General Electric railway converters this variation amounts to about a 50 per cent. change of wattless current between no load and full load; that is, if one of these machines is running at unity power factor, no load, its series field will automatically draw about 50 per cent. leading current at full load: or if the machine is running with about 50 per cent. lagging current at no load it will run at unity power factor when fully loaded; always provided, of course, that the shunt field rheostat setting is not altered between no load and full load. By 50 per cent. leading or lagging current is meant a leading or lagging kv-a. input equal to about 50 per cent. of the kilowatt rating of the converter. The one load at which the converter reaches unity power factor depends altogether upon the setting of the shunt field rheostat: this setting also affects the d.c. voltage. If, for example, the shunt field is adjusted for unity power factor at no load, the d.c. voltage will be considerably higher (about 50 to 75 volts) than if set for unity power factor at full load. Therefore, at a given d.c. voltage the load giving unity power factor depends greatly upon the delivered a.c. voltage; that is, upon the transformer ratio and primary voltage.

Unfortunately, many railway converters are connected to transformers giving a secondary voltage lower than that required. While converter ratios vary somewhat (owing mainly to differences in the length of pole arc), thus making these figures somewhat variable, 370 volts for three-phase and 430 volts for six-phase converters at no load are generally too low for best operation at 600 volts d.c. These low a.c. voltages compel the operation of the converter at about unity power factor, no load, when delivering 600 volts d.c.; a condition calling for 50 per cent. leading current at full load, this current greatly increasing the armature heating just at the time when the armature is least able to stand it.

Transformers with these rated voltages are fitted with primary taps intended to deliver 370 or 430 volts low tension under load when the primary voltage is less than rated owing to primary line drop. These taps are rarely used, the transformer thus delivering 370 or 430 volts no load, and less at under load.

Much more unfortunately, it is common practice to run over-voltage on the d.c. side. It appears to be a common weakness among substation operators to run 5 to 10 per cent. above rated pressure. This is done, of course, by increasing the shunt field excitation to such an extent that the shunt field alone draws a leading current at no load, over and above which the series field adds another leading current as the load comes on. The result of such operation is to practically double the average heating in the armature conductors at full load over and above that of unity power factor, on which the converter guarantees are based. More than this, such operation runs up the heating of certain bars near the collector ring taps to 3 or 4 times the normal amount. This is, of course, over and above the heating resulting from increased core loss in the armature due to over voltage. The result is to practically cut down the capacity of a converter some 30 to 50 per cent. In other words, a customer purchases a converter rated at, let us say, 750 kw., with the usual railway guarantees, and so operates it as to make it only a 500 or 300 kw. converter on the same heating basis. In most cases the average load is so low that no trouble is experienced, but as systems grow and load factors improve, the difficulty is liable to appear.

The proper cure for this evil is to utilize the taps in the primary transformer windings, so as to deliver an a.c. voltage sufficiently high; and to compel the operators to run the d.c. voltage sufficiently low to cause the machine to draw a considerable lagging current at no load, thus cutting down the leading current at full load. For converters in interurban work with low load factors, the lagging current at no load should be about 25 per cent. in kv-a. of the kilowatt rating of the converter. This adjustment will give unity power factor at about half load—which is usually above the average load—and a leading kv-a. input of 25 per cent. at full load; this value increasing at overloads; but doing no harm owing to the limited amount of overload running in such service. However, a d.c. pressure of 625 volts or more, from 370 or 430 volts a.c., is liable to throw solder from bars near the ring taps with a few seconds of heavy overload running.

A contributory source of trouble of this kind is the use of power factor indicators. When a substation attendant starts up a converter with a power factor indicator connected to it, he invariably adjusts the field rheostat for practically unity power factor. At no load this means, of course, a very small wattless current. If the transformer ratio is right for 600 volts, this is done by running up to 625 or higher, which action is right in line with the above mentioned weakness of substation attendants. The danger of this practice is not indicated by the power factor indicator, which at best goes down only to 97 per cent. leading with a 25 per cent. wattless current at full load. Usually, the power factor indicator, when connected on the line side of the equipment, simply indicates the input to the transformer and converter unit as a whole, which at full load is frequently as high as 97 per cent.; whereas the power factor of the converter alone is as low as 90 per cent. giving the excessive overheating above mentioned. This discrepancy is due to the fact that the lag in transformers, or transformers and reactive coil, partly balances the lead in the converter, giving a misleading indication, as the instrument reading is usually taken to mean the power factor of the converter alone.

To overcome these disadvantages, the Railway Engineering Department of the General Electric Company uses, instead of power factor indicators, the so-called wattless meter, connected across the converter collector rings and giving in actual kv-a. the lagging or leading input to the machine. With such an instrument, a converter with no current in its series field should show, for interurban work, about 25 per cent. lagging kv-a. input; that is to say, a 1000 kw. converter should show an input of about 250 kv-a. lagging. A converter of the same rating in city service should show from 350 to 500 kv-a.; these figures being much more easily worked to than the hard off-scale reading which a power factor indicator would give under the same conditions. In small stations, however, no instrument of this kind is necessary, as primary ammeter reading is sufficiently accurate. For example, a 300 kw. converter on a 33000 volt system (full load current about six amperes) should have a lagging input of 1½ to 2 amperes at no load.

MOTOR-DRIVEN AIR COMPRESSORS

By W. E. Miller

It is not generally appreciated how important a part the motor-driven air compressor plays in the efficient operation of electrical railroads. The size, weight and speed of most modern electric cars require that a constant air supply be provided on the car, to eliminate stops for taking in air and to secure the maximum of safety to the public by insuring that full air pressure be always available for the brakes. These requirements are fulfilled by the motor-driven air compressor; and as experience has proved its reliability for the most exacting railway service, practically all motor cars, except some small cars used in city service, are equipped with this device.

While the older types of motor-driven air compressors were efficient machines and operated satisfactorily, their good points depended chiefly on details of construction and on the grade of material used in manufacture. Hence marked improvements were only possible through radical changes in design; especially in reference to oiling, location of gears, and accessibility and cleanliness of the various parts.

With the advent of 1200 volt operation on direct current railroads, which system promises to solve many of the long distance transportation problems and requires the maintenance of rapid schedules such as can only be obtained by the aid of motor-driven compressors, a new design of compressor was all the more important—one which would not limit the construction of the motor, thus enabling it to be manufactured to combine high efficiency, sparkless operation, and durability at the higher voltage.

The General Electric Company has therefore recently designed a new type of air compressor for electric cars. These new compressors, which are all of the same general construction, are manufactured in three sizes for 600 volt service and are designated as follows: CP-27, CP-28, and CP-30, rated respectively at 15 cu. ft., 25 cu. ft., and 35 cu. ft. piston displacement. While primarily designed for use on electric cars and locomotives, they are equally well suited for stationary work in any service where an intermittent supply of compressed air is required.

General Construction

In this type of compressor, as shown in the illustrations, the frame casting completely encloses all working parts, including the motor and crank shaft bearings. To this frame is securely bolted the motor frame, which only supports the pole pieces and brush-holders. The gear is located in the middle of the crank shaft, the gearing being entirely enclosed in the crank case, thus eliminating the necessity of a separate gear case. With this construction, it will be appreciated that the dimensions of the motor are not limited by the distance between gear centers. The motor has therefore been designed with electrical characteristics best suited for the service required.

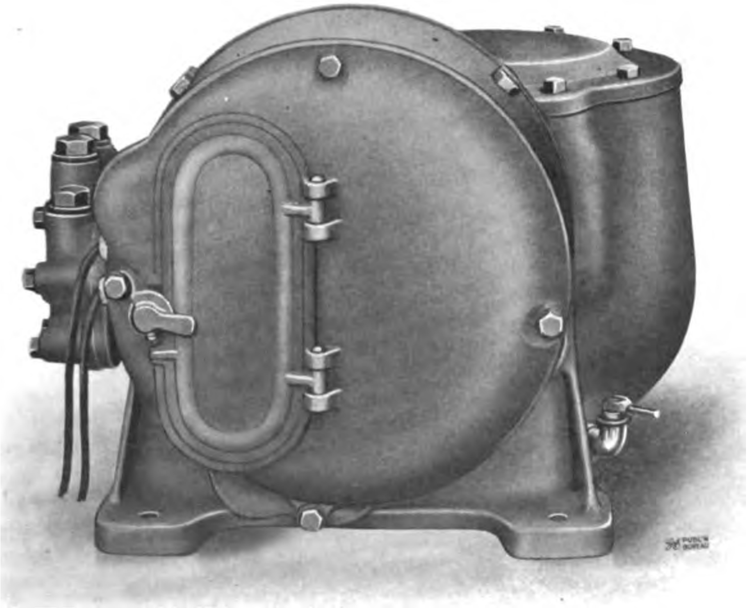
Motor

Since the dimensions of the motor are not limited by mechanical considerations, it is possible to use four salient poles, as in railway motors. Better commutation is thus obtained than is possible with the consequent pole construction now in general use. The motor frame is an independent cylindrical steel casting, securely bolted to the compressor. Four laminated steel pole pieces are bolted to the motor frame, each by two bolts, the heads of which are on the outside of the frame where they are readily accessible. The four field coils are held by spring steel flanges clamped in place by the pole pieces.

The armature is of standard railway construction, and the end windings are thoroughly protected against mechanical injury. The commutator is large to provide for long life, and the brush-holders are well insulated from the frame, the creepage distance between the brush-holder and frame being unusually large. The brush-holders are readily adjustable for wear of the commutator, and are interchangeable.

The armature and the interior of the motor are protected from oil by deflectors on the armature shaft, which divert into a pocket any oil that may pass the motor bearing; from this pocket the oil returns to the crank case through a hole entering the case below the oil level. The oil therefore acts as a seal, effectually preventing oil vapor from entering the interior of the motor. A light framehead cover is bolted to the motor, thoroughly protecting the interior of the motor; and in this framehead, in a position immediately accessible from the side of the car, a dust proof door closed by a cam locking device is provided. This door permits convenient inspection of the brushes or commutator. The interior of the motor frame is free from pockets and can be thoroughly and quickly cleaned by an air blast.

The armature can be readily removed by taking off the motor framehead, turning the brush-holders back, and loosening the pinion nut, without having to touch the crank shaft or gear. This operation can be quickly performed by one man.



Motor End of Air Compressor

Compressor Frame

The compressor frame consists of a single casting containing all bearings for both the motor and crank shafts. A large opening is located directly over the crank shaft and is provided with a removable cover to permit of convenient inspection of the gearing, connecting rods and crank shaft. This cover is slightly larger than the top of the crank case, which construction considerably facilitates its removal. The two cylinders, which form an integral part of the frame casting, project horizontally and thus afford the maximum of heat dissipation.

The cylinder heads are formed by a single casting, secured to the cylinders by tap bolts, one inlet and one outlet valve being provided for each cylinder. The valves operate in a vertical position and are of the tubular type. The intake air passages have liberal areas and are arranged so that the air may be taken from the inside of the car, where it is clean. An air strainer is provided for the receiving end of the intake pipe.

The vent to the crank case opens to atmosphere on the bottom side of the compressor, where it is impossible for dirt to collect and work into the machine. A stand pipe rises from this vent hole, into a large hood or pocket in the frame casting, making impossible the escape of oil through the pipe. A drain plug is provided at the bottom of the frame casting, so located as to drain the crank case when this is desired.

Bearings

All bearings for both the motor and compressor are liberal in size. The bearings for the crank shaft and connecting rods are supplied with hinged caps. After removing the armature and taking off the crank chamber cover, the crank shaft can be immediately removed by swinging up these caps and then lifting the crank shaft out.

Lubrication

All bearings and working parts are automatically lubricated from one source — a well formed in the compressor frame immediately below the gear. This oil well is supplied through one oil filler, consisting of a projecting elbow fitted with a handle plug so designed that any dirt collected around it is lifted off when it is unscrewed, thus preventing the dirt from entering the oil hole. This oil filler is immediately accessible from the side of the car, and of such a height as to insure the proper oil level in the crank case. The driving gear picks up oil from the well and throws it in a steady stream into an oil pan on the under side of the crank chamber cover. Oil distribution to the various bearings is effected through large channels formed in the oil pan.

The illustration on page 434 clearly shows the action of the gear in throwing the oil into the cover, and the distribution to the bearings. No oil waste or oil rings are used, and there are no pipes or small holes to become clogged with sediment or thick oil.

The oiling system is positive in action, and delivers oil continuously to the bearings; the oil flowing back into the well after having done its work. So long as oil remains in the well, all parts of the compressor are perfectly lubricated.

Gears

The gearing consists of a single gear and pinion having accurately cut herringbone teeth; the pinion being secured to the armature shaft on a taper fit, allowing the armature to be readily removed after loosening the pinion nut. The gear is made of forged rims which are riveted together and bolted to a central hub made in one piece with the forged steel crank shaft; this construction enabling the gear to be readily replaced at small cost.

The gear and pinion are located centrally between the cranks, with the pinion above the gear center; the armature and crank shaft bearing pressures are therefore practically constant in direction, reducing noise and vibration. Hence wear on the bearings is reduced, and smooth running with an efficient driving arrangement is obtained.

No special gear case is required, absolute protection from dirt and dust being afforded by the crank case. The absence of a gear case greatly facilitates the removal of the crank shaft for purposes of inspection or repair, and at the same time prevents oil leakage.

Since the crank shaft and armature shaft bearings are located in the same casting, the most accurate mesh of the gear with the pinion is obtained.

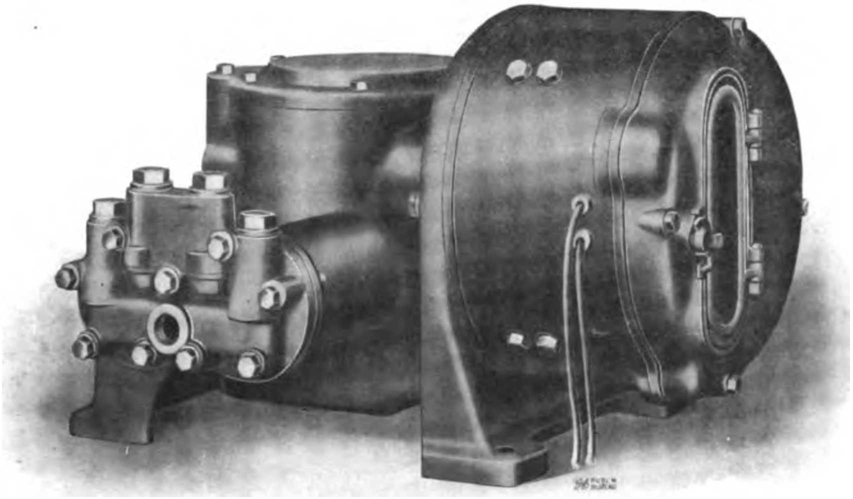
Operation

Standard compressors are provided with series wound motors and can be furnished for operation at 600, 250, and 125 volts. They are intended to operate on an intermittent basis, the total running time not to exceed 30 minutes in each hour.

1200 Volt Direct Current Compressors

Compressors of the above type are also manufactured in the 25 ft. and 35 ft. sizes, for use on 1200 volt direct current railway systems. This type of compressor is particularly adapted for this service on account of its unrestricted motor design, which permits of providing correct electrical constants, ample insulation, and sufficient air space around the commutator and brush-holders to insure safety and reliability at the higher voltage.

Compressors can be operated at 1200 volts for a total of 30 minutes out of each hour, and will operate at approximately half speed on 600 volts for a period of 50 minutes out of each hour when used in service requiring both 1200 volt and 600 volt operation.



Motor Operated Air Compressor for Electric Railway Cars

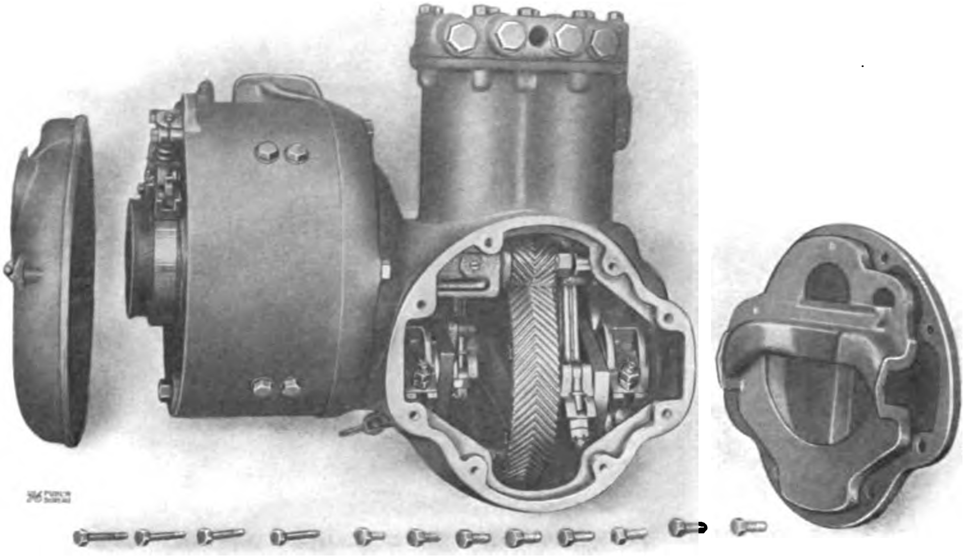
Suspension Cradle

Where compressors for railway service are suspended underneath the car body, a light but rigid cradle made of wrought iron bars is provided. The suspension does not interfere with the accessibility of any part of the compressor that may require inspection and largely reduces the transmission of any noise or vibration to the car framing. The cradle may be easily removed from the car without disturbing the supporting brackets, which are lagged to the car framing.

The switch is of the magnetic blow-out type and, together with an enclosed fuse, is contained in a metal box thoroughly lined with fireproof insulation. Both switch and fuse are readily accessible for inspection or replacement through a hinged cover, which is held closed by a simple latch.

General Dimensions, Weights, Speeds and Capacities

The general dimensions, weights, speeds and capacities of the CP-27, CP-28 and CP-30 compressors are given below when working against a tank pressure of 90 lbs. per sq. in.



Air Compressor with Frameheads Removed

Auxiliary Equipment

For use in connection with these compressors, the General Electric Company manufactures air compressor governors to automatically start and stop the compressor so as to maintain a predetermined pressure in the air reservoirs. These governors are of small and compact design, positive and reliable in operation, and require practically no attention. No starting box or external resistance is required for the compressors.

A combined switch and fuse may be furnished for disconnecting the compressor and governor from the operating circuit.

	CP-27	CP-28	CP-30
Piston displacement, cu. ft. per min.	15	25	35
Voltage	600	600	600
R.p.m. of compressor	200	203	132
R.p.m. of motor	1100	1100	1025
Amperes input, approx.	4.3	7.0	8.5
Cylinder diameter	4⅛	4¾	5½
Stroke of pistons	4⅞ in.	6 in.	7 in.
Intake pipe	1 in.	1¼ in.	1½ in.
Discharge pipe	¾ in.	1 in.	1¼ in.
Length over all	29 in.	33⅝ in.	36¼ in.
Width over all	25 in.	29 in	33$\frac{1}{16}$ in.
Height over all	18 in.	20⅞ in.	24⅛ in.
Weight, approx., lb.	575	880	1100

THE SEWELL'S POINT COAL PIER OF THE VIRGINIAN RAILWAY

BY JOHN LISTON

In order to secure speed and economy in the trans-shipment of coal in large quantities, the Virginian Railway has recently constructed a modern coal handling pier at its seaboard terminal, located on Hampton Roads, at Sewell's Point, Va.

Side View of the Coal Pier from Shore End

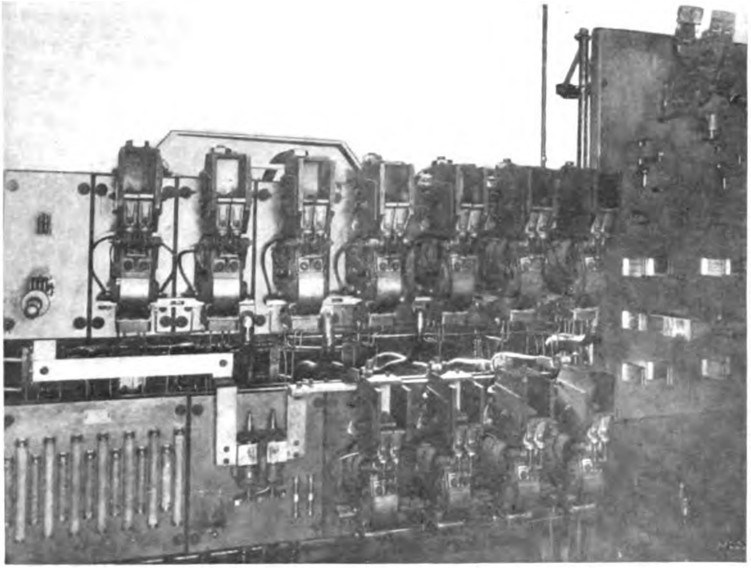
This pier is 1045 feet long from bulkhead to out-shore end, 65 feet wide, and 76 feet high at the in-shore end, from which point it slopes to a height of 69 feet at the out-shore end. Except for the trestle approaches at the in-shore end, which are constructed of timber, the pier is built entirely of heavy structural steel erected on substantial concrete foundations; it has a greater capacity than any other pier on the Atlantic coast, and can deliver 1500 tons of coal per hour to vessels, or a total of 4,500,000 tons per year of 300 ten-hour working days. This does not represent the limit of its capacity, as it is at present equipped with only one car dumper, which meets the present requirements and handles one 50 ton car every two minutes. The remainder of the pier equipment could readily handle double the present quantity if an additional car dumper were installed. The normal operating output of the pier can be, and occasionally is, augmented by coaling vessels at night. All of the machinery used in handling the coal is electrically operated, and both the pier and terminal yards are lighted by means of arc lamps.

The following outline of the methods employed in handling the coal, from the time it leaves the mines until it is received by the collier or steamship, indicates the thorough manner in which the various factors that ordinarily add a large percentage to the first cost of coal have been considered, and shows the economy that has been obtained by providing at the terminal an unusually complete mechanical equipment, which is especially designed for this class of work and which is practically automatic in operation.

The Virginian Railway is primarily a single-track coal transporting road, although some passenger traffic is handled. The road is 442 miles long, and extends inland from Sewell's Point to Deepwater, near Charleston, W. Va., tapping an extensive coal mining region. At Princeton, W. Va., 350 miles from the seaboard, a large gathering yard has been provided where the product of the various mines, located along the main and branch lines, is assembled for shipment to the coast in 80 car trains.

In order to have the cars suitable for carrying return freight, a gondola type of car is used instead of the usual "hopper" coal car, this feature rendered it necessary to provide apparatus for dumping the cars at the terminal pier.

When the trains arrive at the terminal yards at Sewell's Point, the cars are classified and are then run into a gravity yard and dropped one at a time to the foot of an incline, after which they are lifted to the car dumper platform by an electric "mule" or "barney" hoist. Upon arriving on the dumper platform the car is firmly gripped by huge steel clamping arms; the platform is then tilted sideways and finally turned upside down, with a total turn of 115 degrees, thereby instantly dumping the entire contents of the car into a special steel conveyor car which runs on a track located below the dumper.



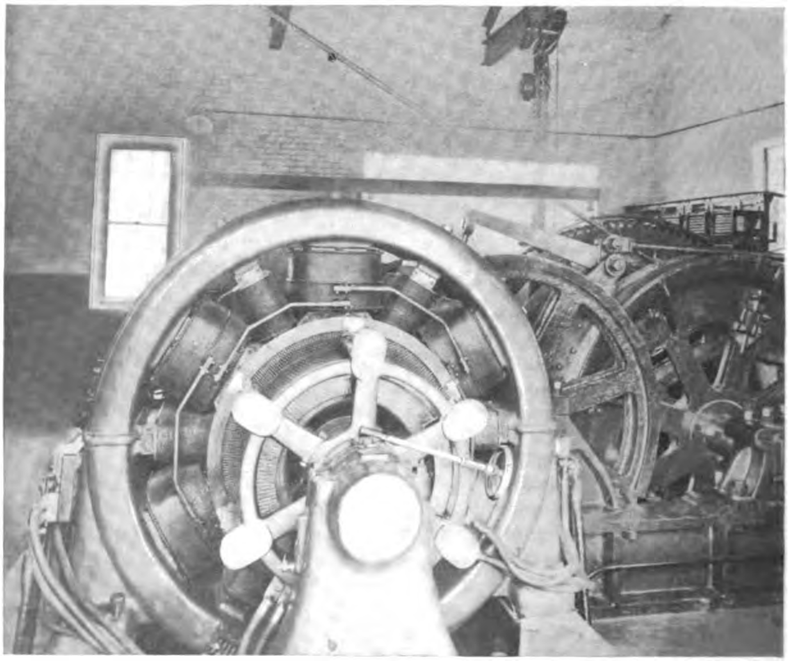
Switchboard and Contactor Control Panels for Main Hoist

When the next loaded car is pulled onto the dumper, it pushes the empty car from the platform, whereupon it travels by gravity into the empty receiving yard, where the service cars are assembled in trains to be returned to the mines. The car dumping process is electrically operated throughout, and is under the control of one man.

The pier is provided with 10 of the special conveyor cars referred to above; these are made of steel with hopper bottoms, and have a carrying capacity of 60 tons each. They are motor-driven and are provided with an air compressor outfit for controlling the brakes and for operating the "hopper" bottoms of the car. An operator's cab is located at each end of the car. Current is received through an overhead trolley system.

After receiving the coal at the dumper, the conveyor car travels by its own power over an automatic scale, where it is weighed without being stopped. The cars are all of the same weight, which fact simplifies the weighing of the coal, as the tare weight of the cars is set on the tare beam of the scales, and the automatic weighing machine records only the net weight of the coal in the cars.

After leaving the scale the car runs to the foot of the long incline on the main pier, where it passes over a "barney" pit sunk between the tracks, in which the "barney" car is located. The main hoist starts the "barney" car, which runs from the pit on a narrow gauge track laid between the conveyor car rails. The push bar of the "barney" car comes in contact with the rear coupling of the conveyor car and pushes it up the incline to



Side View of Main Hoist showing One of the General Electric D.C. Interpole Driving Motors the deck of the pier. The hoist is then reversed and the "barney" car returns to the pit, ready for the next conveyor car. On arriving at the deck of the pier the conveyor car is switched to one of the two delivery tracks located along the two sides of the pier; and, traveling by its own power, it deposits the coal in the pier hoppers and then returns by gravity on an incline track in the center of the pier to a point near the dumper, when it is ready for the next trip.

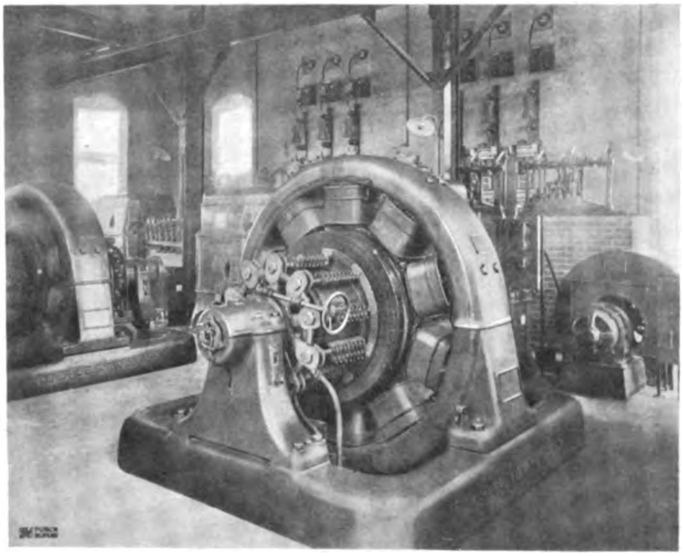
Along each side of the pier there are located 31 coal pockets, each 25 feet from center to center. These pockets have a storage capacity of 60 tons each, and are provided with sliding hoppers and chutes for delivering the coal to vessels. The chutes have a vertical range of 43 feet, and a side range of 25 feet. This range of adjustment permits the delivery of coal to the vessel with a minimum amount of breakage, as the difference in elevation of the vessel, caused by the changing tide or by the weight of the cargo, can be counteracted by adjusting the chutes. The slips on each side of the pier are 150 feet wide and have a depth of 30 feet below mean low water.

Both the pier and receiving yard are lighted by means of 64 G.E. enclosed arc lamps with porcelain enamel reflectors, which provide ample lighting for the operation of the coal handling apparatus at night. These lamps take 6½ amperes at 125 volts, 60 cycles, and as the motors of the coal handling apparatus are all operated on direct current, special lighting transformers for the operation of these lamps are provided in the sub-station, which is located in the terminal yards.

The rapidity with which the coal is handled is evident from the fact that if a ship or barge is coaling while the pier is in operation, the coal can be dumped from the service car, weighed, dumped in the pier hoppers, and chuted to the hatchways in less than five minutes.

Situated below the pier at a point where the main incline meets the pier deck is a neat brick and concrete building which incloses the specially designed main hoist, together with the necessary resistance, contactor control panel, and switchboard.

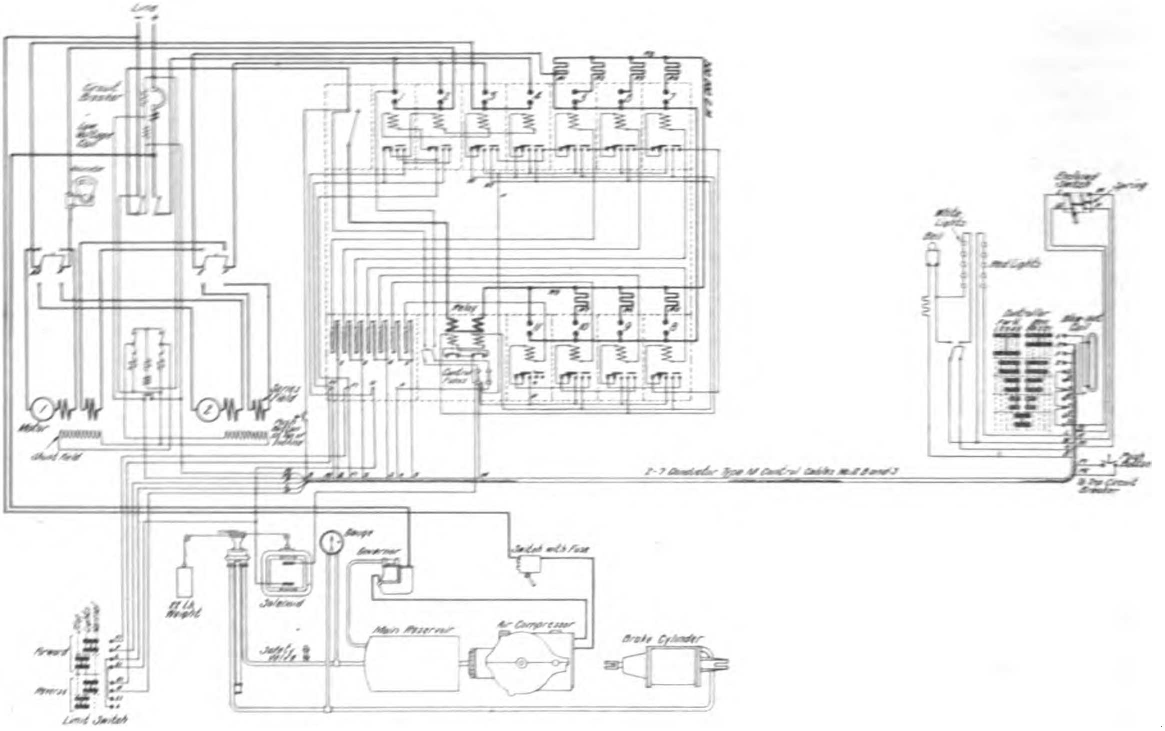
As this is the largest electrically operated hoist ever constructed, the following data may be of interest:



Interior of Terminal Yard Sub-station

The hoist, complete with motors, has a weight of 180,000 pounds and is installed on a bedplate with dimensions of 18 ft. 11 in. by 22 ft. 4 in. All the gears are made of cast steel with cut teeth; the main gear having a diameter of 116 in., a face of 12 in., and teeth of 3½ in. pitch. The main gear, together with the hoist drum, is mounted on the main shaft, which is 12 in. in diameter; the drum having a diameter of 84 in. between flanges. The face of the drum is divided into two sections by a flange, the large section being 42½ in. wide and provided with grooves for the 1¾ in. main hoisting rope. The smaller section is 7 in. wide and grooved for a ¾ in. back haul, or tail rope. The ratio of the gearing between the hoist and the motors is 21 : 1; an intermediate gear of 72 in. diameter, and a pinion of 21½ in. diameter being used.

For the operation of this hoist two direct current General Electric Type MPC motors are provided; one motor driving the hoist and the other being held as a reserve, which can be put into service instantly, if required. These motors are compound wound and are rated at 550 h.p., 550 volt, 525 r.p.m. They are equipped with commutating poles to insure sparkless commutation; this feature


Line
Circuit Breaker
Low Voltage Coil
Ammeter
Motor
Shunt Field
Series Field
Relay
White Lights
Bell
Red Lights
Spring
Blow-out Coil
Push Button
To Trip Circuit Breaker
Gauge
Governor
Switch with Fuse
Solenoid
Weight
Safety Valve
Main Reservoir
Air Compressor
Brake Cylinder
Forward
Reverse
Limit Switch

Wiring Diagram showing Connections and Control System Adopted for the Main Hoist

being especially valuable in this installation, due to the heavy intermittent overloads which the motors have to carry while in service. Both motors are mounted on special bases which are bolted to the hoist base, the motors being located on either side of the hoist and connected with it through gearing.

While these motors are rated at 550 h.p., they are called upon to actually develop 980 h.p. while a conveyor car is being taken up the incline. They have been in operation since April 1st. of this year. An incident which gives an idea of the overload capacity of these motors, occurred when the hoist was accidentally started with the hoist brake set. Under these conditions the motor in operation developed 1250 h.p. without injury.

Located between the two motors and mounted on the hoist base proper is a motor-driven air compressor outfit of General Electric manufacture, similar to those supplied for street railway service. The air pressure developed is 90 pounds per square inch, and the supply is used for the operation of the main hoist brake.

The brake is mechanically set on the hoist drum by a 1400 pound weight, which is held in the "off" position by compressed air while the hoist is in operation, the air being applied by means of a solenoid actuated valve so connected that the brake is automatically released on the first notch of the hoist controller, and automatically set when the controller is in the "off" position.

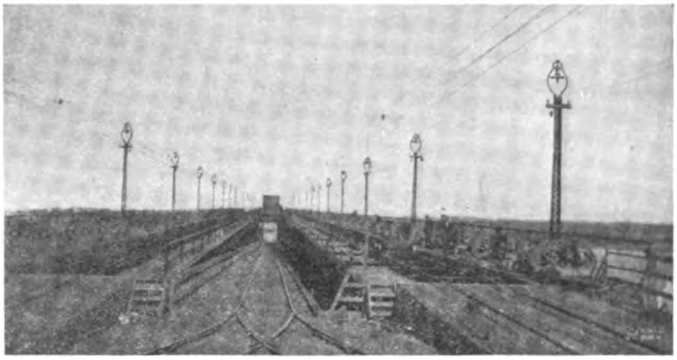
The control equipment includes a switchboard with switches, circuit breaker and ammeter, heavy contactors mounted on a panel, interlocks, controller resistance and relays, and a master type controller. If the field circuits of the motors should be opened during operation, relays serve to throw the motor off the power circuit by tripping the main circuit breaker; and as the solenoid-operated brake valve is connected so that its circuit is made and broken at the same instant as that of the motors, the brake will be automatically set in case of interruption of the motor circuit.

The contactor panel included in this equipment has a larger current carrying capacity than any other of this type heretofore constructed for hoist service.

It is provided with current limit relays, so that it is impossible for the operator to apply more than a predetermined amount of current to the motor during hoisting, although he has full control of it in all other respects.

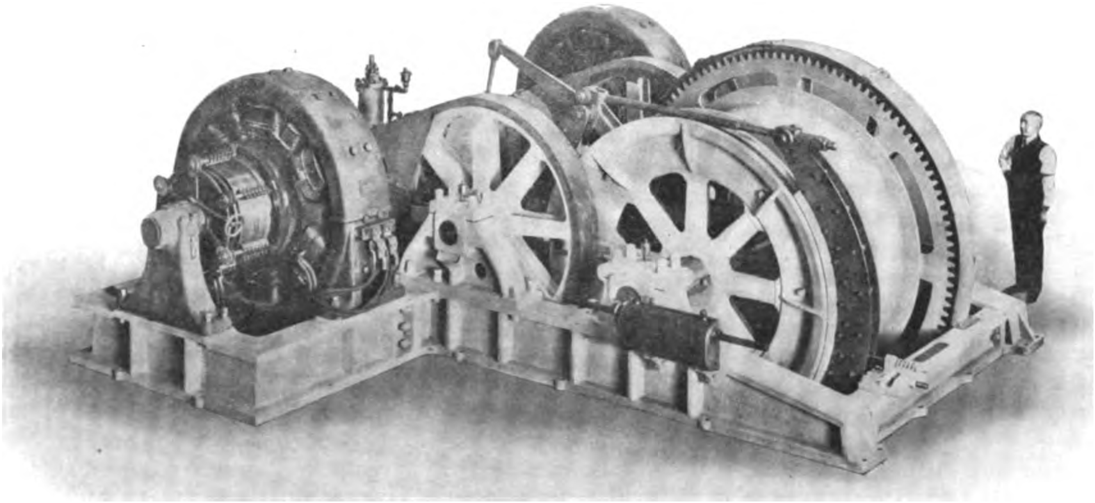
The contactors are of 2500 amperes capacity and are of the same type as those recently supplied by the General Electric Company for the control of 6000 h.p. induction motors in rolling mill service.

The master controller is not located in the hoist house, but has been installed in a small operator's cabin opposite the barney car pit, 350 feet distant from the hoist; by reason of this arrangement the conveyor cars are in full sight of the operator from the time they leave the lower level until they reach the deck of the pier. When a conveyor car reaches a given point near the top of the incline, a limit switch causes a bank of red lamps to light up in the operator's cabin, as a warning to the operator to throw the controller to the "off" position. If, however, for any reason he fails to do this, the limit switch at a given point further on will automatically throw the power off the motor, and thereby set the brakes. It is then impossible for the operator to start the motor in the same direction. The limit switch operates on the down haul in the same way to insure the safe return of the barney car to the pit.



View of Deck of Pier, showing Main Incline Chute Controlling Mechanism and Arrangement of Arc Lamps

It will be seen from the above that every effort has been made to insure the safe and uninterrupted operation of this hoist, which is the most important piece of apparatus in the pier equipment. In service, the hoist can deliver 45 loaded cars per hour, each car averaging 185,000 pounds. The cars are moved up the incline at the rate of 480 feet per minute and the barney car returns to the pit at a speed of 555 feet per minute, the main haul rope unwinding from the drum as the tail rope is wound on. The incline has a 25 per cent. grade, and the vertical distance to which the car is elevated is 77 feet. The main. haul rope of the hoist is 1¾ in.



General View of Main Hoist and Motors

in diameter, 6 strand, 19 wires. The tail rope is also 6 strand, 19 wires, 1¾ in. in diameter, both ropes being made of plow steel.

The hoist, which was especially designed to meet the requirements of this coal pier, was supplied by the Lidgerwood Manufacturing Company of New York, the motors and electric control apparatus being manufactured by the General Electric Company.

Power is secured from the generating station of the Norfolk and Portsmouth Traction Company, located in Norfolk, Va. This station is equipped with General Electric Curtis steam turbine-driven generators, and current is transmitted a distance of ten miles to a rotary converter sub-station located in the receiving yard of the railway terminal. This sub-station is equipped throughout with General Electric apparatus. Current is received at 11,000 volts, three-phase, 60 cycles, and is stepped down through three air blast transformers of 550 kw. capacity, the air blast being supplied by Buffalo blowers driven by G.E. Form K induction motors. The current then passes to three G.E. Type HC, Form P, rotary converters operating at 720 r.p.m., the direct current end delivering 910 amperes at 550 volts; at which voltage the current is supplied to the motors on the pier. Under ordinary conditions only two of these rotaries are in service, the third one being held in reserve.

For the operation of the a.c. arc lamps on the pier and terminal yards, two Type H, Form G, 50 kw., 60 cycle transformers are installed, one of which is held as a reserve. The balance of the station equipment consists of a 16-panel switchboard, necessary oil switches for the incoming line, rotary converters and transformers. These oil switches are all motor-controlled, and a 55-cell storage battery of three amperes capacity is provided for the operation of the motors. The station is provided with multi-gap lightning arresters and is lighted by arc lamps similar to those used on the pier.

The plans of the Virginian Railway for the Sewell's Point terminal include the construction of three additional piers similar in capacity and equipment to the one described above. When the entire development is completed, the terminal will have a normal annual capacity of 18,000,000 tons, and will constitute the largest coal handling plant of this type in the world.

PORTABLE SUB-STATIONS FOR ELECTRIC RAILWAYS

By A. H. Kruesi

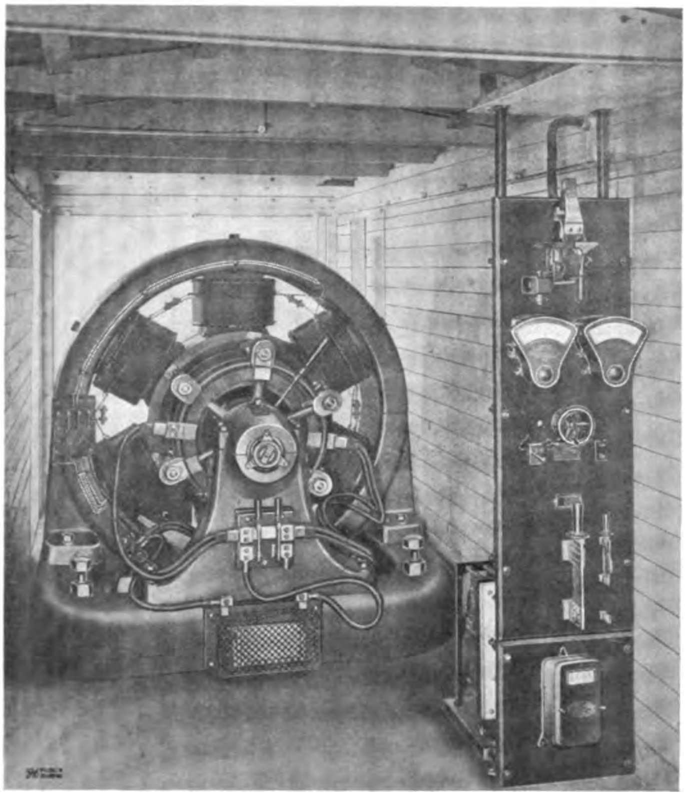
In modern street railway systems employing high tension alternating current power generators and distribution, permanent rotary converter sub-stations are usually located at such points on the line as are required to furnish 600 volt or 1200 volt direct current to the trolley wire with reasonable voltage regulation under the normal service conditions on the particular sections of the line which they feed. In many cases, the normal load on a sub-station can be carried by one rotary converter unit, and frequently no reserve equipment is provided in the sub-station for use in case of accident, or for supplying abnormal current demands.

On the majority of electric roads, there are certain sections of the line on which abnormally heavy traffic must be handled at infrequent intervals or only during a certain portion of the year, as for instance, lines serving fair grounds, parks, or summer resorts, where the heavy passenger traffic only lasts for a few weeks or even for a few days out of the entire year. Often such sections of line are not operated at all, except on those special occasions.

To meet these conditions, either the permanent sub-station equipment must be of much larger capacity than required for the average service, and additional feeder copper installed (and even then the line drop may be excessive when under maximum service conditions), or a temporary sub-station must be installed.

For the supply of intermittent power of the above character and to provide for a temporary supply of power in case of accidents at sub-stations equipped with only one rotary converter unit, the General Electric Company has developed portable sub-stations consisting of specially arranged cars containing complete sub-station equipments, including a rotary converter or motor generator set of the required capacity, transformers, switchboard and accessories. These portable sub-stations are provided with trucks adapted for short radius curves and may be conveniently moved to any section of the line requiring power temporarily, only necessitating making connections to the high tension lines and direct current trolley or feeders, to render them ready for immediate service.

A considerable number of these portable sub-stations have been built for various roads, and they have proved to be a most valuable adjunct to the modern street railway system.



Converter End of Portable Sub-Station, 500 Kw., 600 Volt Converter

1st. For ensuring continuity of power supply with a minimum investment in permanent sub-stations.
2nd. For saving large investment in copper and sub-station equipment on lines heavily loaded only on special days or seasons.
3rd. For providing additional power at any point where the traffic may be temporarily abnormally heavy.
4th. For furnishing power to extensions while under construction.

Limitations of Size

Owing to the limited dimensions of a freight car it is generally impracticable to provide for more than 500 kw. capacity in a single car and the large clearances required for high voltages will probably confine the use of portable sub-stations to transmission voltages of 60,000 volts and less. Even lower limits of capacity may be prescribed by the strength of bridges and culverts on the railway on which the car is to be used.

Equipment

Portable sub-stations are generally provided with a rotary converter equipment, interchangeable with that used in the permanent sub-stations. Such an equipment for either 25 or 60 cycles consists of the following principal items:

Rotary Converter.
Step-Down Transformers.
Reactive Coil.
Blower if Transformer is Air-Blast type.
Switchboard Equipment.
Lightning Arresters for Line Potentials of 13,200 volts or less.

Special conditions may make motor generators more desirable in certain cases, when the equipment comprises:

Motor-Generator Set.
Step-Down Transformer if Line Voltage exceeds 13,200 Volts.
Blower if Transformer is Air-Blast type.
Switchboard Equipment.
Lightning Arrester for Line Potentials of 13,200 Volts or less.

Converters

The General Electric Company standard rotary converter with speed limit attachment is used with slight modifications. The commutator end of the base is provided with leveling bolts to facilitate leveling the converter for operating when the car is located on a grade. Special attention is given to the balancing of the converter armature to minimize vibration of the car.

The converter is securely fastened to the car floor framing with adjustable beveled wooden blocks fitted to the inside of the base frame to prevent shifting of the converter while the car is in transit.

The equalizer switch is mounted on the pillow block instead of the field frame on account of the limited width of the car, as shown in the illustrations.

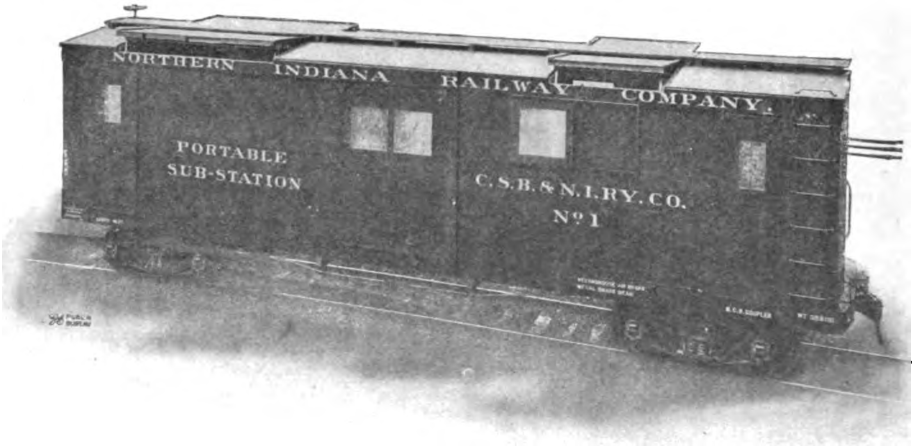
The standard reactive coil with starting panel as designed for permanent sub-stations is used without any modifications. The reactive coil is usually of the air blast type. Air is supplied by the blower through an air duct formed on the car floor.

Transformers

Transformers are generally of the air blast type, this type being particularly suitable on account of its light weight per unit of output. They are usually made top connected for the high potential leads, and bottom connected for the low potential leads which are carried through the false floor forming the air blast chamber to the reactive coil and starting panel, which are also mounted on this floor. For potentials above 33,000 volts, oil cooled transformers must be used and on account of the small clearances between the transformer and car walls, in some cases it is necessary to employ a blower to give a positive direction to the air currents and secure effective cooling by preventing pockets of hot air from forming which would otherwise exist in the limited space available.

Lightning Arresters

It is considered safe to install multi-gap lightning arresters inside the car for line potentials of 13,200 volts and less, the car walls and ceiling being lined with asbestos lumber in the vicinity of the arresters. Arresters for higher voltages should not be placed inside the car on account of fire risk. In this case, if the car is used adjacent to a permanent sub-station, the lightning arresters there installed may provide protection. But, if the car is used some distance from any permanent sub-stations for a considerable time, so that lightning protection is required, the arresters should be mounted outside and away from the car.



Portable Sub-Station for the Chicago, South Bend & Northern Indiana Railway Co.
300 Kw. Capacity, 45,000 Volts

Switchboard

The switchboard for a converter equipment consists of:

1 Incoming line and transformer panel.
1 D.C. converter and feeder panel.
1 Converter starting panel.

Panels are made of natural black slate and the instruments have a dull, black finish.

Three-Phase Incoming Line and Transformer Panel

Size of panel 76 in. high, 16 in. wide.
Equipment:
1 Hand operated T.P.S.T. oil switch with transformer trip.
1 Ammeter.
1 Current transformer.
1 Low potential transformer (for 60 cycle converter only).
1 High potential transformer (for 60 cycle converter only).
1 Synchronism indicator (for 60 cycle converter only).
1 Synchronizing plug and receptacle (for 60 cycle converter only).
3 Enclosed fuses for blower motor.

D.C. Converter and Feeder Panel.

Equipment:
1 Carbon break circuit breaker with low voltage release.
1 Ammeter.
1 Voltmeter.
1 Hand-operated field rheostat.
1 Integrating wattmeter.
1 S.P.S.T. main switch.
1 S.P.D.T. lighting switch.
2 Potential receptacles with 1 plug.
1 D.C. lightning arrester.

1 S.P.4T. starting switch (for 60 cycle converter only).
1 Starting resistance (for 60 cycle converter only).
1 S.P.S.T. equalizer switch (mounted on converter frame).

Three-Phase Converter Starting Panel Mounted on Reactance.

For 25 cycle converters up to 500 kw.

Equipment:
1 D.P.D.T. lever switch.

Six-Phase Converter Starting Panel Mounted on Reactance. For 500 kw. 25 cycle converters.

Equipment:
1 T.P.D.T. lever switch for fractional voltage taps.
1 T.P.D.T. lever switch for full voltage leads.

Arrangement of Apparatus

The positions of the switchboard panels are shown in the plan and elevation diagram on page 472. The oil switches are located at the end of the car, thus obtaining a short and direct run of high tension connections, and isolating them from the attendant whose operating position will be in the center of the car.

The incoming high tension lines may be connected directly to the transmission line, but if frequent or continued use of the portable sub-station in one locality is necessary, disconnecting switches should be mounted on the nearest pole to facilitate disconnecting the oil switch without having to cut off power from the transmission line.

The transformers and the converters which constitute the bulk of the weight are placed directly over the trucks to relieve the car body of heavy loads.

The car is protected above and at the side of the circuit breaker by asbestos lumber from any arcing which may result from the opening of the circuit breaker on short circuits or overloads.

The positive feeder cable is carried to a terminal block on the outside of the car near the roof for convenient connection to the trolley wire or feeder. The negative cable is securely grounded to both trucks. No connection is made to the equalizer switch on the converter, but if the converter does not take its share of the load when used near another sub-station, a temporary connection can readily be made to the equalizer bus in the station.

Car Construction

The bodies of portable sub-station cars equipped by the General Electric Company have been constructed of wood because of the relatively small cost and quicker delivery. These cars are generally lined inside and in some cases the lining is covered with asbestos lumber.

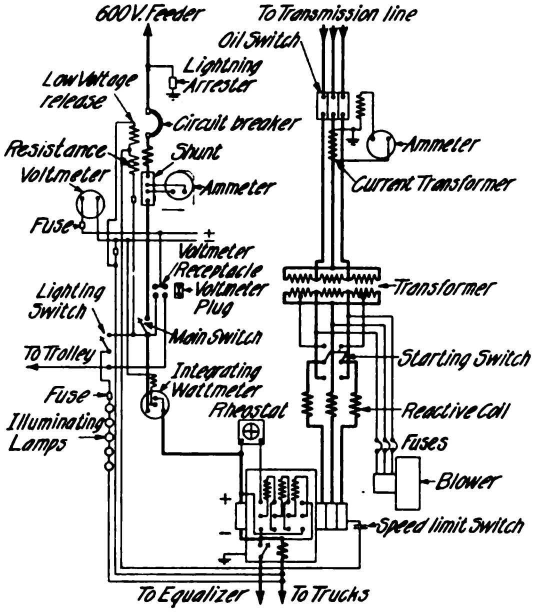
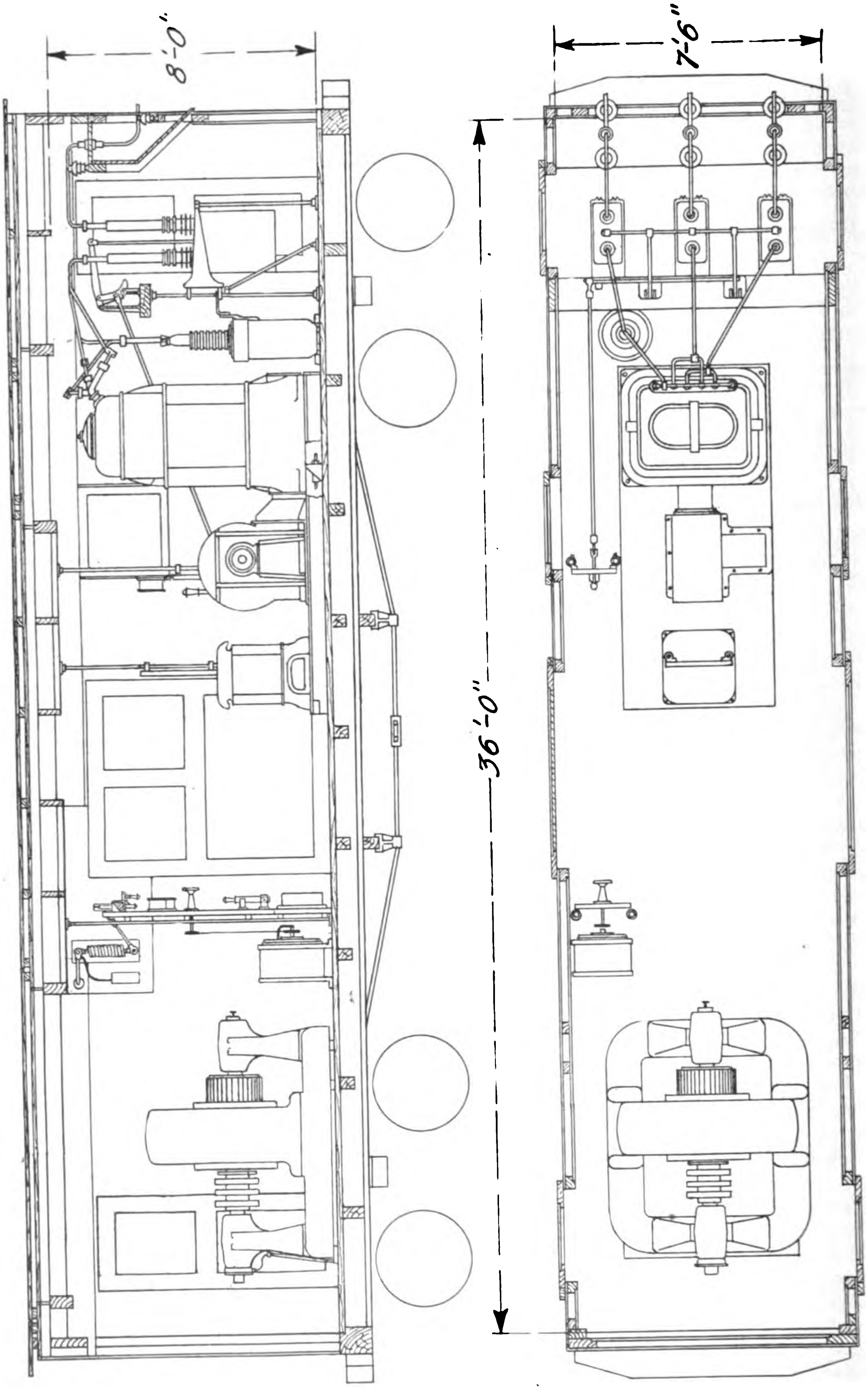

600V. Feeder
To Transmission line
Oil Switch
Lightning Arrester
Low Voltage release
Circuit breaker
Resistance
Shunt
Ammeter
Voltmeter
Ammeter
Current Transformer
Fuse
+
Voltmeter Receptacle
Voltmeter Plug
Transformer
Lighting Switch
Main Switch
To Trolley
Integrating Wattmeter
Starting Switch
Fuse
Rheostat
Reactive Coil
Illuminating Lamps
Fuses
Blower
+
−
Speed limit Switch
To Equalizer
To Trucks

Diagram of Connections

For line potentials above 33,000 volts, steel cars are considered more suitable, but the interior of such a car will be hotter when exposed to the sun than that of a wooden car and special provision for ventilation is required. As will be seen from the illustrations the car is an ordinary freight car with standard trucks, hand and air brakes but is provided with hatches, windows and additional doors. The hatch covers, over the transformer and converter, hinge at the center line of the roof on a removable beam, so that the whole hatch can be lifted when installing or dismantling apparatus or it may be raised on either side depending on the weather conditions to provide for ventilation immediately over the apparatus. These hatches are provided with wide over-lapping edges so that they may be kept open, except in severe weather. When closed they form a waterproof joint with the roof of the car.



Plan and Elevation of Portable Sub-Station, 300 Kw. Capacity, 33,000 Volts

The high tension entrance end of the car is specially constructed to form a weather protection over the line entrance bushings. The opposite end of the car is detachable to facilitate the removal of apparatus if no crane is available and end doors as well as center doors are provided to give adequate ventilation on the ends of the car, to give access to oil switches and high tension insulators at one end and to the collector rings, etc., of the apparatus at the other end of the car without having to pass through the narrow aisles. All doors are fitted with wire glass sash in the upper panels, arranged to be pivoted or lowered for ventilation.

Illumination at night is obtained from rows of incandescent lamps near the roof connected in groups of five in series either to the converter or the trolley by a single-pole double throw lighting switch on the D.C. panel.

Car Equipment

As cars must be shipped over steam railroad lines to their destination, they are provided with MCB equipment throughout, including air brakes acting on all wheels. A hand brake shaft is usually provided at one end, operating the brakes on one truck only. If the car is required to pass around curves of very short radius, a special construction of the brake rigging to permit the trucks to swivel may be required, differing from the usual steam railroad brake rigging. Draft gear is of the MCB standard type with MCB standard couplers and hand levers at the side of car. Bodies should have the usual steps, ladders, etc.

The trucks are usually of the diamond frame arch bar type equipped with 33 in. wheels mounted on MCB standard steel axles and fitted with cast iron journal boxes. Unless a more elaborate finish is desired, the outside of the car is given three coats of paint and the interior is left unpainted.

Size and Weight

A portable converter sub-station for 13,200 volts and 300 kw. capacity will have an interior length of approximately 36 ft., width 7 ft. 6 in., and height 8 ft., and will weigh, complete, about 76,500 lbs. For 33,000 volts and 500 kw. capacity, the interior dimensions will be approximately, length 40 ft., width 8 ft. 6 in., height 9 ft., and weight about 97,000 lbs. A 60,000 volt, 60 cycle portable substation with oil cooled transformer, Form K 10 oil switches and 500 kw. induction motor-generator installed in a steel car will have interior dimensions of 50 ft. length, 8 ft. 6 in. width, 9 ft. 3 in. height and a weight of approximately 150,000 lbs. On account of the size of high tension entrance bushings, they are designed for placing in the roof, and are lifted out before shipment on account of passage through tunnels, etc., the holes being temporarily closed.

Installation

The car body and trucks can be purchased directly according to the customer's own specifications or the car complete with equipment can be supplied by the General Electric Company. In either case, if the installation is done by the General Electric Company, the car should preferably be shipped to the Company's Schenectady Works for installing the apparatus.

The high tension insulators are mounted on metallic pins fastened to steel or metal covered supports, the metal being thoroughly grounded to the trucks to reduce fire risk in case of a failure of the insulation. The entrance bushings are similarly supported and the supports are grounded to the framing. The small wires are run in iron pipe conduits under the car floor, except the lighting circuits where insulated wire run on porcelain knobs is used. The heavy cables are supported in porcelain clamp insulators and bushings, either under the false floor of the air blast chamber or below the car floor and between the longitudinal stringers. The space between stringers is boarded up to protect the cables from wheel splash.

Data for Quotations

Inquiries which require the car to be furnished by the electrical manufacturer should state:

Minimum clearance on local tracks.
There may be less clearance on the purchaser's local tracks than on the various lines over which the car would pass to its destination. This data should be given in the usual way; *i.e.*, the different permissible widths for various heights above the track.
Minimum radius of curve around which car must pass.
Where the apparatus will be installed.
Steel or wood box desired.
Special requirements.

If the car is to be furnished by the customer and the installing done by the electrical manufacturer, the latter should be supplied with drawings of the car indicating the interior dimensions and arrangements for line entrances and how the apparatus is to be put into the car; that is, whether through hatches or removable end or side doors.

PORTABLE ELECTRICAL MEASURING INSTRUMENTS

By J. A. Haraden

It has become common practice in talking of electricity meters to make a distinction between indicating and recording meters. The indicating device, which indicates the instantaneous value of the circuit, is known as an instrument, while the integrating or recording device, which registers on a dial the total energy consumption, is commonly known as a meter. In considering portable instruments the information that can be obtained from manufacturers' catalogues and bulletins is general, and in many cases is not specific enough to enable one who is not familiar with instruments to determine just what specifications will best suit the requirements at hand. In the following article the characteristics of various types of modern instruments are described.

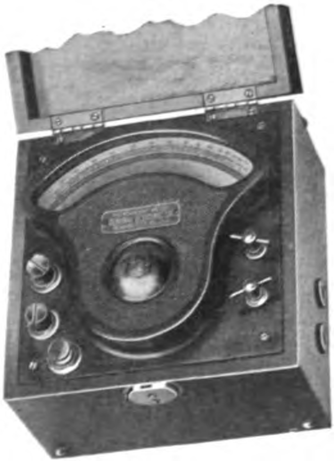


Fig. 1. Type P-3 Portable Meter

While it is possible to obtain good results on direct current with instruments of the dynamometer type or inclined coil type, the most satisfactory ones for all direct current work are those of the D'Arsonval type. Instruments of this class consist of a permanent magnet and a moving coil of wire, which is generally wound on an aluminum frame. In instruments of the best construction, the moving coil, or armature, is of extremely light weight, weighing less than 2.0 grammes. The air gaps are very short and the clearances small. It is therefore possible to obtain full scale deflection of the needle with extremely low current, and, owing to the light weight armature, the Foucault currents set up in the aluminum frame are sufficient to render the indications very dead beat. Some of the necessary features of a good instrument of this type are:

1st, permanency of magnet

2nd, accuracy of calibration and scale marking

3rd, permanency of control springs

4th, good mechanical construction

5th, high grade workmanship in manufacture

6th, magnetic shielding.

All of the above points have to be considered and the absence of any one renders the instrument either unsatisfactory or absolutely worthless. For example: if the magnets are of poor stock, or are not properly aged, their strength will decrease and the instrument will read low.

In many cases, experience with an instrument is the best method of determining its worth, but information in regard to certain features, such as accuracy of calibration, workmanship and construction, can be obtained by a careful inspection and test of the instrument at hand.

The most satisfactory instruments for alternating current work are of the dynamometer construction, which generally consists of two stationary coils enclosing a moving coil to which is attached the indicating pointer. Other alternating current instruments are of the inclined coil, repulsion, and induction types.

Inclined coil and repulsion type instruments having a moving element of soft iron are quite satisfactory for alternating current ammeters and voltmeters in which a moderate degree of accuracy is satisfactory. They have frequency and wave form errors, but in a properly designed instrument these errors are small and are practically negligible for ordinary variations found in common practice. Instruments of this type should not be used on direct current where accuracy better than one per cent. is required. Inclined coil voltmeters and wattmeters with wire wound armatures are very satisfactory for general testing, and, for a moderate price instrument, give excellent results. They are free from frequency and wave form variations and can be used on direct current by taking reversed readings.

Induction type instruments can be used only on the alternating current and have inherent errors which are higher than those of any of the above mentioned varieties. In general construction these comprise a set of laminated iron punchings, on which is wound an exciting coil and a moving element, the latter consisting of a metal disc or drum. A turning moment is exerted on the metal armature by a copper shading coil, or other similar device, which progressively shifts the flux across the air gap in the iron laminæ. These instruments have to be used on circuits having approximately the same frequency as that for which they are calibrated, and although they are satisfactory for switchboard instruments and have exceptionally long scales, which subtend an angle of 300 degrees, they are not especially good portable test instruments.

General Electric Co's. New Portable Instruments

The most modern ideas in the design of electrical testing instruments are embodied in the new G.E. portable instruments, Type P–3 and Type DP, shown in Fig. 1 and Fig. 2 respectively.

The P-3 ammeters, voltmeters, single and polyphase wattmeters are designed primarily for alternating current work; but the voltmeter and single-phase wattmeters, being of the dynamometer type, can be used on direct current without error and without taking reversed readings. The ammeters are of the inclined coil type with iron armatures and should not be used on direct current when accuracy better than one per cent. is required.

The dynamometer is a recognized standard for electrical measurements, and the General Electric Type P–3 voltmeters and wattmeters embody all the desirable features for general testing and laboratory work. They are extremely accurate, well damped and magnetically shielded. As compared with other precision instruments, they are equally accurate, lighter in weight and much more easily read, as well as cheaper. Instruments of the Kelvin balance type, although accurate, are not magnetically shielded, and, owing to the extremely heavy moving element and zero reading needle, they are difficult to read where there is any vibration, and on fluctuating circuits.

The P–3 instruments, together with portable potential and current transformers, will be found very satisfactory for testing induction motors. A very convenient and useful outfit for polyphase motor testing is a P-3 polyphase wattmeter and two variable ratio Form P current transformers. This outfit makes it possible to obtain the input of a motor on a single scale, and the various capacities of the transformer make it applicable to a wide range.

The transformers are arranged with multiple wound primary windings, which can be readily connected for machines of different capacities. The Form P is made in two capacities; one has a range of 25, 50, and 100 amperes, and the other, 50, 100, and 200 amperes. For higher capacities, the Form R current transformer can be furnished. This transformer has no primary winding, but by threading cable through the core various ratios can be obtained. The transformer is rated 1000: 5 for one turn; *i.e.*, with one wire passing through the core and carrying 1000 amperes, there will be 5 amperes in the secondary winding; with two turns the capacity is 500 amperes.

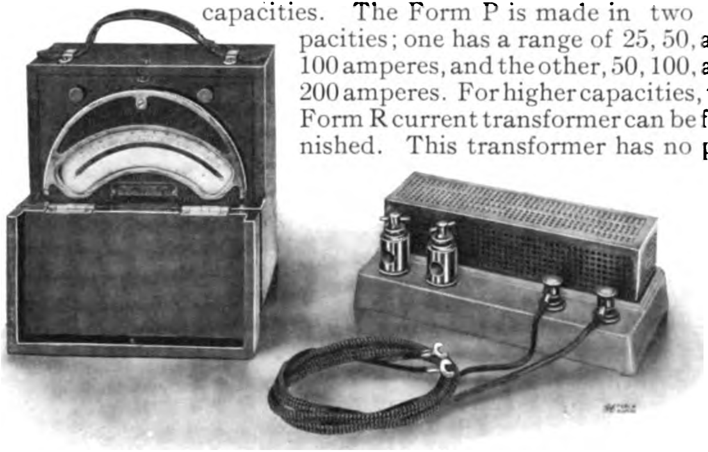


Fig. 2. DP Portable Meter and Shunt

The Type DP ammeters, voltmeters, millivoltmeters and mil-ammeters are strictly direct current instruments of the permanent magnet D'Arsonval type. In keeping with instruments of this class they give the best results for direct current work and will be found to have extremely low internal losses, very light moving elements and very dead beat pointers. Unshielded instruments of this type are particularly susceptible to influence by external magnet fields and any mass of magnetic material. Even the earth's field will produce a small error in such instruments. The General Electric Type DP instruments are enclosed in a soft drawn steel case which gives ample shielding.

A very convenient set of instruments, and one which will cover a large range of work, is a 150, 300, and 750 volt voltmeter and a millivoltmeter with one or more combination shunts. Two triple-rated shunts will cover a range of 0.1 to 300 amperes with capacities so that good readings are always obtained.

THE THIRTIETH CONVENTION OF THE ASSOCIATION OF EDISON ILLUMINATING COMPANIES

By W. S. Andrews

The thirtieth Convention and twenty-fifth annual meeting of the Association of Edison Illuminating Companies was held at Briarcliff Lodge, Briarcliff Manor, N. Y., from Aug. 31st to Sept. 2nd inclusive. More than two hundred delegates and guests attended this Convention, which was one of the most successful and enjoyable that has been held since the Association was founded in 1885.

A large number of highly interesting and most valuable papers were read and discussed at the various sessions, which were held in the morning and evening of each day, thus leaving the afternoon hours free for social pleasures.

A special concluding feature of this Convention was a reception and banquet given to Mr. and Mrs. Edison to commemorate the thirtieth anniversary of the Edison incandescent lamp, Mr. Edison having made his first practical incandescent lamp in 1879.

The central dining table was seventy feet long by forty feet wide, around which were seated Mr. and Mrs. Edison, the guests of honor, officials and delegates of the various Companies, and other guests, including a number of Mr. Edison's pioneer associates to whom special invitations had been issued for the occasion.

Thomas A. Edison

The entire dining room was magnificently decorated with flowers, among which roses were predominant, and it was most artistically lighted by about five thousand miniature incandescent lamps entwined in the flower garlands and so skillfully arranged throughout the room that the illumination was perfect, without being conspicuous in any particular place.

Mr. W. W. Freeman, the retiring President of the Association, occupied the chair, with Mr. and Mrs. Edison on either side. After-dinner speeches were made by the Chairman, Mr. Samuel Insull, Mr. E. W. Johnson, Mr. F. P. Fish and Dr. C. P. Steinmetz. It would naturally be impossible in this brief notice to give even a resumé of what was spoken in eulogy of Mr. Edison's superlative genius, but an important point that was emphasized by Dr. Steinmetz in regard to the Edison Incandescent Lamp may be fittingly mentioned.

Dr. Steinmetz spoke in part to the following effect:

"It is a remarkable evidence of Mr. Edison's transcendent genius that his original carbon filament incandescent lamp exists today unchanged in all of its really important features.

"It is true that the use of filaments of tantalum, tungsten and other highly infusible metals has greatly increased the efficiency of our modern lamps, but these changes must be properly classed as incidentals which do not affect the fundamental principles governing his original invention. Neither is it any disparagement to his ability as an inventor that he did not make use of the metallic filaments referred to, for reason that the science of electro-chemistry with all the wonderful products of the modern electric furnace had no existence in the days of his early invention. Furthermore, it is quite within the limits of possibility that the carbon filament may eventually be so improved as to outclass even the best of the metallic filaments that are known today, so that the incandescent lamp of the future may perhaps be identical in all respects, even to its filament, with the original lamp which Mr. Edison produced thirty years ago."

The function was concluded by Mr. W. W. Freeman conducting to the chair the newly elected President of the Association of Edison Illuminating Companies, Mr. F. E. Murray, President of the New York Edison Ill'g. Co., who closed the Convention of 1909 with a few appropriate remarks.

CAPACITY

TABLE XVI

Microfarads per 1000 Feet of Circuit Formed by Two Aerial Wires
(2000 Feet of Wire)

STRANDED CABLES

$$C = \frac{0.003677}{\log\left(\frac{D-r}{r}\right)}$$

Interaxial Distance, Inches	SIZE OF WIRE													
	500,000	450,000	400,000	350,000	300,000	250,000	0000	000	00	0	1	2	3	4
1	.02325	.01810	.01517	.01277	.0109	.00932	.00830	.00717	.00639	.00579	.00522	.00480	.00447	.00417
2	.00624	.00590	.00564	.00534	.00505	.00474	.00450	.00420	.00395	.00374	.00352	.00333	.00319	.00304
3	.00459	.00444	.00428	.00412	.00395	.00377	.00363	.00343	.00327	.00313	.00298	.00285	.00274	.00263
4	.00390	.00378	.00368	.00356	.00344	.00331	.00320	.00305	.002925	.002810	.00269	.00258	.00250	.00241
5	.00360	.00341	.00333	.00323	.00313	.00303	.00294	.00281	.00271	.002610	.002505	.002414	.00234	.00226
6	.00324	.00316	.00309	.00301	.002925	.00286	.00275	.00264	.00255	.002467	.00237	.002290	.00223	.002157
9	.00278	.00272	.00267	.00261	.00255	.00248	.00242	.00234	.002266	.002200	.002126	.002060	.002010	.001950
12	.00253	.00248	.00244	.00229	.00234	.00228	.00223	.00216	.00210	.002043	.001980	.001925	.001880	.001828
18	.00225	.00221	.00218	.00214	.00210	.00206	.00301	.001956	.001907	.001860	.001805	.001760	.001722	.001680
24	.00209	.002055	.00203	.001996	.00196	.00192	.001884	.001832	.00179	.001748	.001700	.001660	.001626	.001588
30	.00198	.00195	.00192	.001893	.00186	.001825	.001793	.001748	.001708	.001670	.001628	.001590	.001560	.001525
36	.00190	.00187	.001846	.00182	.00179	.001755	.001725	.001684	.001646	.001612	.001572	.001538	.001508	.001475
42	.00183	.001807	.001786	.00176	.001732	.00170	.001674	.001633	.001597	.001566	.001530	.001496	.001467	.001437
48	.00178	.001757	.001736	.001712	.001686	.001656	.001628	.001593	.001560	.001528	.001493	.001460	.001434	.001410
54	.00174	.001714	.001696	.001672	.001647	.001620	.001593	.00156	.001526	.001496	.001462	.001432	.001406	.001378
60	.00170	.00168	.001660	.001637	.001613	.001586	.001562	.001528	.001497	.001468	.001435	.001406	.001382	.001355
72	.00164	.00162	.00160	.00158	.00156	.001534	.00151	.00148	.00145	.001425	.001394	.001365	.001342	.001316
84	.00159	.001573	.001556	.001537	.001516	.001493	.00147	.00144	.001413	.001388	.001358	.001333	.001310	.001285
96	.00155	.001535	.00152	.00150	.00148	.001457	.001437	.001408	.001382	.001358	.00133	.001305	.001283	.001260
108	.00152	.001502	.001487	.00147	.00145	.001428	.00141	.001382	.001356	.001333	.001305	.001282	.001260	.001238
120	.00149	.001475	.00146	.001443	.001425	.001403	.001384	.001358	.001333	.001310	.001285	.001260	.001240	.001218
132	.001466	.00145	.001437	.00142	.001402	.001382	.001363	.001338	.001314	.001292	.001266	.001244	.001218	.001202
144	.001445	.00143	.001415	.00140	.001382	.001362	.001345	.001318	.001295	.001275	.001250	.001228	.001208	.001189
156	.001425	.00141	.001397	.00138	.001365	.001345	.001327	.001303	.001280	.001260	.001235	.001213	.001195	.001175
168	.001407	.001393	.00138	.001365	.001348	.001330	.001312	.001288	.001266	.001245	.001222	.001200	.001183	.001164
180	.001390	.001377	.001365	.00135	.001333	.001315	.001297	.001275	.001253	.001233	.001210	.001190	.001170	.001152

TABLE XVII

INDUCTIVE REACTANCE

STRANDED CABLES

25 Cycles

Ohms per 1000 Feet of Stranded Cable (for one wire)

Interaxial Distance, Inches	SIZE OF WIRE													
	500,000	450,000	400,000	350,000	300,000	250,000	0000	000	00	0	1	2	3	4
1	.0119	.0124	.0130	.0136	.0143	.0152	.0160	.0171	.0182	.0193	.0204	.0216	.0227	.0238
2	.0185	.0190	.0196	.0202	.0209	.0218	.0226	.0237	.0248	.0259	.0270	.0282	.0293	.0304
3	.0224	.0229	.0235	.0241	.0248	.0257	.0265	.0276	.0287	.0298	.0309	.0321	.0332	.0343
4	.0251	.0256	.0262	.0266	.0275	.0284	.0292	.0303	.0314	.0325	.0336	.0348	.0359	.0370
5	.0273	.0278	.0284	.0290	.0297	.0306	.0314	.0325	.0336	.0347	.0558	.0370	.0381	.0392
6	.0290	.0295	.0301	.0307	.0314	.0323	.0331	.0342	.0353	.0364	.0375	.0387	.0398	.0409
9	.0329	.0334	.0340	.0346	.0353	.0362	.0370	.0381	.0392	.0403	.0414	.0426	.0437	.0448
12	.0357	.0362	.0368	.0374	.0381	.0390	.0398	.0409	.0420	.0431	.0442	.0454	.0465	.0476
18	.0395	.0400	.0406	.0412	.0419	.0428	.0436	.0447	.0458	.0469	.0480	.0492	.0503	.0514
24	.0423	.0428	.0434	.0440	.0447	.0456	.0464	.0475	.0436	.0497	.0508	.0520	.0531	.0542
30	.0444	.0449	.0455	.0461	.0468	.0477	.0485	.0496	.0607	.0518	.0529	.0541	.0552	.0563
36	.0461	.0466	.0472	.0478	.0485	.0494	.0502	.0513	.0524	.0535	.0546	.0558	.0569	.0580
42	.0476	.0431	.0487	.0493	.0500	.0509	.0517	.0528	.0539	.0650	.0561	.0573	.0534	.0595
48	.0489	.0494	.0506	.0506	.0513	.0522	.0530	.0541	.0552	.0563	.0574	.0586	.0597	.0608
54	.0500	.0505	.0511	.0517	.0524	.0533	.0541	.0552	.0663	.0574	.0586	.0597	.0608	.0619
60	.0510	.0515	.0521	.0527	.0634	.0543	.0551	.0562	.0573	.0584	.0595	.0607	.0618	.0629
72	.0528	.0533	.0639	.0543	.0552	.0561	.0569	.0580	.0591	.0602	.0613	.0625	.0686	.0647
84	.0543	.0548	.0554	.0660	.0667	.0576	.0584	.0595	.0608	.0617	.0628	.0640	.0681	.0662
96	.0555	.0560	.0566	.0572	.0579	.0586	.0596	.0607	.0618	.0629	.0640	.0652	.0663	.0674
108	.0566	.0571	.0577	.0583	.0500	.0599	.0607	.0618	.0629	.0640	.0651	.0663	.0674	.0685
120	.0576	.0581	.0587	.0593	.0500	.0509	.0617	.0628	.0659	.0650	.0651	.0673	.0684	.0695
132	.0585	.0590	.0596	.0602	.0609	.0618	.0626	.0637	.0648	.0659	.0670	.0682	.0693	.0704
144	.0594	.0599	.0605	.0611	.0618	.0627	.0635	.0646	.0557	.0668	.0679	.0691	.0702	.0713
156	.0601	.0605	.0612	.0618	.0625	.0634	.0642	.0668	.0664	.0675	.0586	.0698	.0709	.0720
168	.0608	.0613	.0619	.0625	.0632	.0641	0649	.0650	.0671	.0682	.0693	.0705	.0716	.0727
180	.0615	.0620	.0626	.0632	.0635	.0640	.0666	.0667	.0678	.0689	.0700	.0712	.0723	.0734

Single Conductor.

INDUCTIVE REACTANCE

TABLE XVIII

STRANDED CABLES

60 Cycles

Ohms per 1000 Feet of Stranded Cable (for one wire)

Interaxial Distance, Inches	SIZE OF WIRE													
	500,000	450,000	400,000	350,000	300,000	250,000	0000	000	00	0	1	2	3	4
1	.0286	.0297	.0311	.0326	.0344	.0365	.0384	.0411	.0437	.0464	.0491	.0519	.0545	.0572
2	.0445	.0456	.0470	.0485	.0503	.0524	.0543	.0570	.0596	.0625	.0650	.0678	.0704	.0731
3	.0538	.0549	.0563	.0578	.0596	.0617	.0635	.0668	.0689	.0716	.0743	.0771	.0797	.0824
4	.0664	.0615	.0629	.0644	.0662	.0683	.0702	.0729	.0755	.0782	.0809	.0637	.0863	.0890
5	.0655	.0668	.0650	.0695	.0713	.0734	.0753	.0780	.0806	.0833	.0860	.0888	.0914	.0941
6	.0696	.0707	.0721	.0736	.0754	.0775	.0794	.0821	.0847	.0874	.0901	.0929	.0955	.0982
9	.0790	.0801	.0815	.0830	.0848	.0669	.0888	.0915	.0941	.0968	.0995	.1023	.1049	.1076
12	.0855	.0866	.0830	.0895	.0913	.0934	.0953	.0580	.1066	.1033	.1060	.1058	.1114	.1141
18	.0948	.0959	.0973	.0968	.1006	.1027	.1046	.1073	.1099	.1126	.1153	.1181	.1207	.1234
24	.1014	.1028	.1039	.1054	.1072	.1093	.1112	.1139	.1165	.1192	.1219	.1247	.1273	.1300
30	.1065	.1076	.1090	.1105	.1123	.1144	.1163	.1190	.1216	.1248	.1270	.1298	.1324	.1351
36	.1107	.1118	.1132	.1147	.1165	.1186	.1205	.1232	.1258	.1285	.1312	.1340	.1366	.1393
42	.1143	.1154	.1168	.1153	.1201	.1222	.1241	.1268	.1294	.1321	.1348	.1376	.1402	.1429
48	.1173	.1184	.1198	.1218	.1231	.1252	.1271	.1298	.1324	.1351	.1378	.1406	.1432	.1459
54	.1200	.1211	.1225	.1240	.1258	.1279	.1298	.1325	.1351	.1378	.1405	.1433	.1459	.1486
60	.1225	.1236	.1350	.1265	.1283	.1304	.1323	.1350	.1376	.1403	.1430	.1458	.1484	.1511
72	.1267	.1278	.1252	.1307	.1325	.1346	.1365	.1392	.1418	.1445	.1472	.1500	.1526	.1553
84	.1302	.1313	.1327	.1342	.1360	.1381	.1400	.1427	.1453	.1480	.1507	.1535	.1561	.1538
96	.1332	.1343	.1357	.1372	.1390	.1411	.1480	.1457	.1433	.1510	.1537	.1565	.1591	.1618
108	.1360	.1371	.1385	.1400	.1418	.1439	.1458	.1485	.1511	.1538	.1565	.1593	.1619	.1646
120	.1383	.1394	.1408	.1425	.1441	.1462	.1481	.1508	.1534	.1561	.1588	.1616	.1642	.1669
132	.1405	.1416	.1430	.1445	.1462	.1484	.1503	.1530	.1556	.1583	.1610	.1633	.1664	.1691
144	.1425	.1436	.1450	.1465	.1433	.1504	.1523	.1550	.1576	.1603	.1630	.1658	.1684	.1711
156	.1443	.1484	.1468	.1485	.1501	.1522	.1541	.1568	.1594	.1621	.1648	.1676	.1702	.1729
168	.1480	.1471	.1485	.1500	.1518	.1539	.1558	.1585	.1611	.1638	.1665	.1693	.1719	.1746
180	.1476	.1487	.1501	.1516	.1534	.1558	.1574	.1601	.1627	.1654	.1681	.1709	.1735	.1762

Single Conductor

TABLE XXIX

INDUCTIVE REACTANCE

STRANDED CABLES

X .6283L
L Millihenries

Ohms per 1000 Feet of Stranded Cable (for one wire)

100 Cycles

Interaxial Distance, Inches	SIZE OF WIRE 500,000	450,000	400,000	350,000	300,000	250,000	0000	000	00	0	1	2	3	4
1	.0476	.0495	.0518	.0544	.0574	.0608	.0639	.0684	.0728	.0772	.0818	.0864	.0908	.0952
2	.0741	.0760	.0783	.0809	.0839	.0873	.0904	.0949	.0993	.1037	.1083	.1129	.1173	.1217
3	.0896	.0915	.0938	.0964	.0994	.1028	.1059	.1104	.1148	.1192	.1288	.1284	.1328	.1372
4	.1006	.1025	.1048	.1074	.1104	.1138	.1169	.1214	.1258	.1302	.1348	.1394	.1438	.1482
5	.1092	.1110	.1134	.1160	.1190	.1224	.1255	.1300	.1344	.1588	.1434	.1480	.1524	.1568
6	.1160	.1179	.1202	.1228	.1258	.1292	.1323	.1368	.1412	.1456	.1502	.1548	.1592	.1636
9	.1317	.1336	.1359	.1385	.1415	.1449	.1480	.1525	.1569	.1613	.1659	.1705	.1749	.1793
12	.1425	.1444	.1467	.1493	.1523	.1557	.1588	.1633	.1677	.1721	.1767	.1813	.1857	.1901
18	.1580	.1599	.1622	.1648	.1678	.1712	.1743	.1788	.1832	.1876	.1922	.1968	.2012	.2056
24	.1690	.1709	.1732	.1758	.1788	.1822	.1853	.1898	.1942	.1986	.2032	.2078	.2122	.2166
30	.1775	.1794	.1817	.1843	.1873	.1907	.1938	.1983	.2027	.2071	.2117	.2163	.2207	.2251
36	.1845	.1864	.1887	.1913	.1943	.1977	.2008	.2053	.2097	.2141	.2187	.2233	.2277	.2321
42	.1905	.1924	.1947	.1973	.2003	.2037	.2068	.2113	.2157	.2201	.2247	.2293	.2337	.2381
48	.1955	.1974	.1997	.2023	.2053	.2087	.2118	.2163	.2207	.2251	.2297	.2343	.2387	.2431
54	.2000	.2019	.2042	.2068	.2098	.2132	.2163	.2208	.2252	.2296	.2342	.2385	.2432	.2476
60	.2040	.2059	.2082	.2108	.2138	.2172	.2203	.2248	.2292	.2336	.2382	.2428	.2472	.2516
72	.2110	.2129	.2152	.2178	.2208	.2242	.2273	.2318	.2362	.2406	.2452	.2498	.2542	.2586
84	.2170	.2189	.2212	.2238	.2268	.2302	.2333	.2378	.2422	.2466	.2512	.2558	.2602	.2646
96	.2220	.2239	.2262	.2288	.2318	.2352	.2383	.2428	.2472	.2516	.2562	.2608	.2652	.2696
108	.2266	.2285	.2308	.2334	.2364	.2398	.2429	.2474	.2518	.2562	.2608	.2654	.2698	.2742
120	.2306	.2325	.2348	.2374	.2404	.2438	.2469	.2514	.2558	.2602	.2648	.2694	.2738	.2782
132	.2341	.2360	.2383	.2409	.2439	.2473	.2504	.2549	.2593	.2637	.2633	.2729	.2773	.2817
144	.2375	.2394	.2417	.2443	.2473	.2507	.2538	.2583	.2627	.2671	.2717	.2763	.2807	.2851
156	.2405	.2424	.2447	.2473	.2503	.2537	.2568	.2613	.2657	.2701	.2747	.2793	.2837	.2881
168	.2433	.2452	.2475	.2501	.2531	.2565	.2596	.2641	.2685	.2729	.2775	.2821	.2865	.2909
180	.2460	.2479	.2502	.2528	.2558	.2592	.2623	.2663	.2712	.2756	.2802	.2848	.2892	.2936

Single Conductor.

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Photograph of the Honorary Commercial Commissioners of Japan and Officials of the General Electric Company

Taken in front of the Company's Restaurant

GENERAL ELECTRIC
REVIEW

VISIT OF JAPANESE COMMISSIONERS TO THE SCHENECTADY WORKS

On October 11th the Schenectady Works of the General Electric Company were visited by the Honorary Commercial Commissioners of Japan, who devoted the better part of a day to the inspection of the various factories comprising that plant.

The illustration on the opposite page is a reproduction of a photograph taken during their visit, and shows the members of the Honorary Commissioners attended by those officials of the General Electric Company who accompanied them on this occasion.

The Commission, consisting of thirty-nine members, comprises some of the foremost statesmen, financiers, and scholars of the Japanese Empire. Nine are members of the Japanese Parliament, three being of the House of Lords and six of the House of Representatives.

Among the more notable members of the party are:

Baron Eiichi Shibusawa, Chairman of the Commission, and head of the great banking house bearing his name; a man of first prominence in his own country, and a financier and statesman of international reputation. He it was who negotiated the Japanese bonds in that country's recent wars with China and Russia. His influence has been greater than that of any other person in modernizing the business methods of Japan.

Baron Kanda, a graduate of Amherst College, and one of the most prominent educators in Japan.

Mr. Kojiro Matsukata, a ship builder, graduate of Yale University, and President of the Kobe Chamber of Commerce.

Mr. K. Otani, member of the House of Peers, and President of the Yokohama Chamber of Commerce.

After the inspection of the Works and the luncheon served in the Company's restaurant, the party visited the American Locomotive Works and Union College, and in the evening attended a dinner given in their honor by the General Electric Company, President Charles A. Coffin presiding.

In the introductory speech of the evening, President Coffin traced the friendly influence of America in the history of Japan, and spoke of the resulting mutual regard in which the two nations hold each other.

He also drew attention to the remarkably rapid progress made by Japan in both political and industrial fields. Speaking of the latter, he said "'Life without industry is a crime, and industry without art is a crime' you have shown both industry and art."

Baron Eiichi Shabusawa spoke in Japanese, his speech being translated by Mr. Nishiike, Secretary of the Kyoto Chamber of Commerce, and a graduate of Yale. The Baron spoke of the surprising size of the General Electric Works, which greatly exceeded his expectations, and mentioned the fact that a large number of Japanese have received their final instruction in practical electrical engineering under that Company's guidance. Other speakers were Baron Naibu Kanda and Professor Morse, of Boston.

During the day the six Japanese ladies who formed a portion of the Commissioners' party were entertained by automobile trips and at luncheon at the home of Vice-President Hinsdill Parsons.

In speaking of this tour of the United States, Baron Shibusawa said that the object of the visit "is to intensify the friendly relations between the two countries, and also to further the Japan-America tradal relations; * * * that they visited America not simply as representative business men, but as representatives of the entire population of Japan, so as to produce a perfect understanding between Japan and America."

CENTRAL STATIONS FOR TOWNS OF 1000 TO 1200 INHABITANTS

With such amazing rapidity has the utilization of electricity grown, that to the electrical engineer of to-day, the name "central station" is apt to carry with it the thought of hundreds, or even thousands of kilowatts generating capacity—capacities utterly undreamed of by our predecessors. There are, however, many relatively small communities scattered throughout the length and breadth of the country, in which central stations of moderate capacity would be welcome and would prove to be lucrative investments.

As pointed out by Mr. Caryl D. Haskins, in his article in this issue, this field has been somewhat neglected, owing to the fact that the large stations have demanded the services of those who have made a specialty of electrical development, and thus absorb the attention of the electrical fraternity more or less to the exclusion of possible minor plants.

The article "Central Stations for Towns of 1000 to 1200 Inhabitants," by Mr. Haskins (than whom none is better qualified to discuss the subject), supplies the necessary preliminary information regarding plants that are suitable to meet the requirements of these smaller communities. The author furnishes estimates of the cost of installing and operating both steam and gas engine plants, for intermittent and for 24 hour service; and shows what incomes may be expected when the plant is intended for commercial incandescent lighting only, and when it is designed to carry in addition either a motor or a street lighting load, or both.

The future development of a plant is often difficult to foresee, very frequently it is far more rapid than would be anticipated, and in many cases much could have been saved had the probable future demands been known at the time of erection.

Mr. Haskins' long experience in the electric lighting industry, coupled with records of the growth of innumerable similar plants, enables him to determine within a fair degree of approximation the probable development of stations of this class.

ELECTRICAL TESTING

The series of articles on commercial electrical testing, commenced in this number of the Review, by Mr. E. F. Collins, Superintendent of the Testing Department of the General Electric Company's Schenectady Works covers a branch of engineering, the study of which is of great importance at the present time. The rapid growth of electrical engineering has necessitated a corresponding development in testing practice to keep pace with engineering and commercial needs, and therefore a description of the arrangements, methods and apparatus used by the Schenectady Works of the largest electrical manufacturing company in this country cannot but prove instructive, not only to the engineering student, but also to all electrical engineers; besides being of considerable aid to those schools and colleges which give a course of instruction in electrical laboratories.

The testing department of a large company is, of necessity, one which employs only those methods which have been found by experience to combine accuracy, efficiency and economy. The subject can be naturally divided into two classes; *viz.*, tests made to obtain engineering information to serve as a basis for future design or for other purposes, and commercial testing. In the latter case, which forms the greater part of the testing work, commercial considerations require that each job be finished as quickly as possible. The machines supplying power and the switchboards must therefore be located and designed from this point of view, and all connections and wiring laid out with the greatest possible care. The personnel must be thoroughly drilled and instructed in their work by experienced men, and each job as it comes along must be assigned to a small group who assume the responsibility for the proper completion of the test. The switchboards must be wired so that a large number of connection combinations can be readily obtained. The instruments used must be of the highest quality to insure accurate results, and must frequently be compared with reliable standards. A standardizing laboratory is necessary for this work. All these matters must be kept in mind and a system provided for enforcing testing regulations for obtaining clear records of the work done. In short, the testing department is a complex organization; its keynote is efficiency. Economy of labor and power, and the arrangement of apparatus is of equal importance with accuracy; with the latter, of course, a *sine qua non*, since the majority of apparatus tested must meet specification as regards performance, heating, efficiency, and the like. When, as often happens, more than one method can be employed in a given case, that test must be chosen which yields the maximum of accuracy practicable, consistent with the character of the work.

These questions are fully considered in these articles and will appeal to all those having charge of similar departments, college laboratories, etc. To the student of engineering, however, the description of the various tests, their preparation, how they are carried out, the instruments used, and the diverse calculations required will appeal most strongly. Nearly all stationary and revolving electrical machinery have been covered, and many examples have been given showing the kind of results that actually obtain in the more important cases, and the means employed for discovering electrical or mechanical faults. The precautions to be observed in the preparation of apparatus for test, and in the proper use of the testing instruments to obtain accurate results will also prove of great value.

Besides electrical machinery, the articles also deal with the testing of steam turbines and engines—gasoline engines—with an account of the work done on the Company's test tracks. The electrical apparatus covered not only includes all kinds of generators, motors, converters, transformers, instruments and switches, but also the following: air brake apparatus, circuit breakers, blowers, electric locomotives, governors, insulators, mercury arc rectifiers, projectors, railway signals, regulators, switchboards, and train control apparatus. It is therefore evident that the series embraces practically the whole field of electrical engineering apparatus, and that the treatment of the subject is comprehensive. As a consequence the value of these articles can hardly be over-estimated.

COMMERCIAL ELECTRICAL TESTING

PART I

BY E. F. COLLINS

SUPERINTENDENT OF TESTING DEPARTMENT

In the manufacture of armatures and fields for electrical apparatus, possible defects in material and errors of workmen can often be disclosed by what may be termed "stationary testing." Defects and errors may arise as follows: Through a wrong application of, or mechanical faults in insulation; the use of wrong material for conductors, leads, etc.; wrong assembly or connections (workmen's mistakes).

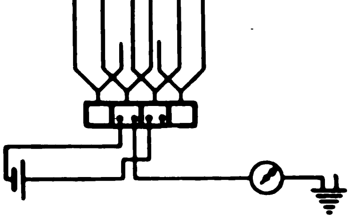


Fig. 1. Testing for Grounds

Direct current armatures are tested for grounds, short circuits, open circuits, and high resistance joints before being sent to the Testing Department. In testing for grounds a high potential is applied between winding and core; the potential depending upon the class of apparatus tested. When a ground develops in test it can usually be located by smoking the insulation at the breakdown point.

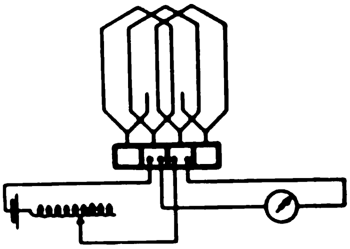


Fig. 2. Testing for Open Circuit

If a low resistance ground has developed it may be quickly and accurately located by the following method: A low voltage current sufficient to give a readable deflection on a galvanometer or millivoltmeter (Fig. 1) is passed through the armature winding from a commutator bar to one adjacent to it. A connection is made from one side of a galvanometer "to ground", the lead from the other terminal of the galvanometer being placed on one of the commutator bars. The supply leads and galvanometer lead are then passed from segment to segment, until first a full deflection is obtained and then zero reading when the leads are moved one segment further.

The grounded coil then lies *between* the bars for which full deflection was obtained.

A bar to bar test is usually made to disclose short circuits, open circuits, and other similar faults. For this test the windings connected to two adjacent commutator segments have their resistance measured by the "drop of potential method," as indicated in Fig. 2. Storage batteries and a special electromagnetic d'Arsonval galvanometer should be used. With this arrangement readings can be obtained rapidly, as the instrument is "dead beat."

Measuring the ohmic resistance of the winding will sometimes reveal a wrong connection, which, on a bar to bar measurement, would give a uniform deflection all around the commutator. Series or wave windings may sometimes have all the conductors joined in series, but in the wrong order, so that the armature is inoperative. In the case of multiple or lap windings, double, triple or even quadruple spiral re-entrant windings are possible, whereas a single spiral is what is wanted. In taking a resistance measurement for brush to brush, or running resistance of the armature, see that the measurement is made from the proper commutator segments. For multiple or lap windings, the resistance measured from diametrically opposite points divided by half the number of poles squared will give the true running resistance, while with a series or wave winding the resistance should always be taken at points 180 electrical degrees apart. For example, take a four-pole armature with a lap winding and 360 commutator segments. This armature should have its resistance measured between bars No. 1 and No. 181. This resistance divided by four will give the running resistance. With a wave winding on the same armature, the resistance measurement should be taken between bars No. 1 and No. 91, this resistance being the true running resistance.

Alternating current armatures and fields are similarly tested for grounds, short circuits, open circuits, wrong connections, polarity, etc. In testing for grounds the same methods and similar apparatus are used as for direct current machines, except that alternating current machines are usually designed for higher voltages, and consequently testing voltages are correspondingly higher, and greater care must be taken in testing. All high potential tests must be made with carefully calibrated electrostatic voltmeters that have been checked with a spark gap. The testing equipment should be as near the apparatus as possible, since the additional capacity of testing lines may raise the voltage at the receiving end much above that at the generating end. Unless this precaution is taken, excessive voltages may be applied which may damage the insulation. In case a ground develops, a resistance measurement will generally locate the point at which it occurs, unless each phase has two or more multiple circuits. In the latter case it may be more readily located by opening one or more cable joints and separating the circuits.

A measurement may then be taken in the following manner: First, measure the total resistance of the grounded circuit or phase; second, measure the resistance of the winding from one terminal to ground, by connecting one side of the measuring line to the terminal and the other side to ground; third, measure the resistance from the other terminal to ground, by shifting the measuring line from the first terminal to the second. If all measurements have been accurately made, the sum of the second and third will be equal to the first, and the location of the ground will be as far from one terminal, expressed in terms of the total length of the winding, as the measured resistance from that terminal to ground is to the total resistance of the circuit.

This test is outlined in Fig. 3, which represents a single circuit, or phase, of an alternating current machine, with a ground at the point X. If the resistance between A and B is one ohm, between A and G 0.35 ohm, and between B and G 0.65 ohm, the location of the ground is 35/100 of the distance between A and B, from A. As 10 coils are in the circuit, the measurements show that the fourth coil is grounded, counting from A.

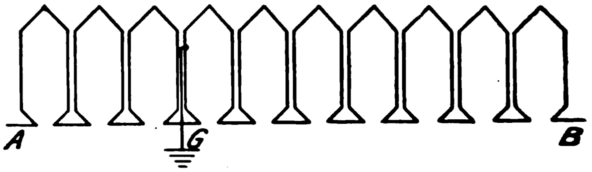


Fig. 3. Test for Grounds on an A.C. Armature

In the case of an alternating current winding the ohmic resistance measurement will not always detect a wrong connection, such as a reversed coil, pole section, or phase; the copper resistance measurement would be correct, although the total winding might be partly reversed and therefore, inoperative. Such faults may be discovered by a polarity or impedance test with alternating current. For this purpose a single-phase current can be used, since a reading may be taken on the different circuits, or between pairs of terminals successively, by shifting the testing lines until the whole winding has been tested.

Short circuited coils on moderate size machines can be readily detected by using a wound electro-magnetic yoke excited with alternating current. This yoke is dropped over a portion of the armature coil after the coils have been placed in their slots. The yoke and armature form an alternating current transformer, with the yoke winding as primary and the armature coil as secondary. If there is a short circuited turn, layer, or coil in the armature, the magnetizing current in the yoke winding rises. If the current is maintained a short time, the insulation on the short circuited section will warm up appreciably, or burn sufficiently to indicate the defective coil.

On larger size alternator armatures, tests may be made for short circuits by passing alternating current through the armature coil itself. In this case it is usually necessary to increase the reactance of the coil by placing a magnetic bridge over its armature slots after it has been assembled in the core.

The above tests may be made with the apparatus at rest, and these faults can be more readily corrected when apparatus is being wound, with a resulting saving in time and cost. However, the test may be equally well employed after the apparatus is completed.

Practically all direct current machines are delivered to the Testing Department unassembled, with few exceptions.

To assemble a machine, the field spools are first mounted upon the frame and connected up in accordance with the connection print which is furnished for each machine. As soon as this is done, the windings are tested electrically for resistance and insulation; the polarity of the poles is also tested by exciting the field coils. These tests check the assembly of spools and their position upon the frame.

In testing field coils for polarity, all field windings must be tested separately to ascertain if the series and shunt commutating pole windings are wound and assembled correctly. Polarity may be tested by means of a compass, in which case the compass must not be carried too near to the pole, otherwise it may be demagnetized or even reversed. To test for opposite polarity of alternate poles, two pole tips may be bridged with a piece of soft iron. If the polarity of the poles differ, the piece will be strongly attracted; whereas, if the poles are of like sign, a much less attraction will be exerted.

On direct current machines, the voltage drop per spool with a given current flowing through the field should not vary more than a few per cent. (maximum to minimum) from the average voltage drop per spool. The field spools for alternating current apparatus are assembled on the field spider in the Armature Department; hence, it is only necessary to take a resistance measurement per spool before starting a test. The variation between maximum and minimum drop per spool should not differ materially from the average drop per spool. In recording the drop on spools, the spools should be numbered in a clockwise direction, beginning at the spool next to the opening in the shunt field when facing the commutator. When testing a machine, a very careful record must be kept of all winding resistances. Many armatures are fitted with equalizing rings, impossible to obtain the true armature resistance without disconnecting the equalizer taps.

The shunt field resistance is obtained by the "drop method," using an ammeter and voltmeter. This measurement is required on each machine before a test is started. For measuring the series field resistance a special galvanometer measuring set is used, with which the various testing sections are provided; this set is described in a later article. As a considerable amount of the resistance of a series field may consist of the contact resistances of the joints between the spools, all connections must be carefully cleaned and clamped tightly together before measuring the resistance.

The measurement of air gaps on all apparatus is important. Air gaps on direct current machines are measured in the following manner: With the armature stationary, the gap under all poles should be measured at both the commutator and pulley ends, the measuring scale being inserted under each pole tip, without including the chamfer of the tip. A mark should then be placed on the armature circumference under a given pole, and the armature revolved through one pole span. The air gap measurement should be taken under every pole tip at the commutator end. The first set of measurements are known as the "stationary gap"; the second set as the "revolving gap."

The maximum air gap on direct current machines, when measured from iron to iron, should not differ from the minimum air gap by more than a few per cent. of the average measurement, and but little more when measured from the armature binding wire to the iron of pole piece.

On commutating pole machines the air gap measurement is taken under the center of the commutating pole. It is also necessary to measure the distance between the tip of each commutating pole and the adjacent tip of the main pole. This spacing should be uniform.

Air gap measurements are taken on alternating current machines in a manner similar to that described above for "stationary" and "revolving gap" on direct current machines; except that the air gap measurement on a.c. machines is taken at the center of the pole piece, both on the front and back ends. In measuring the "revolving gap," it is not necessary to take the air gap measurement at points corresponding to 180 electrical degrees on the surface of the armature. The measurement need only be taken at points spaced 45 degrees apart. That is, eight (8) sets of measurements are required for the "revolving gap.

Since the air gaps of induction motors are small, and a uniform gap is important, they are measured by special gauges provided for the purpose. These gauges are passed completely through the motor air gap from end to end of the punchings, measurements being taken at several points about the circumference of the rotor while stationary and while revolved in a manner similar to that described above.

When air gap measurements are taken, a critical inspection should be made of the clearance between the rotor and windings or other parts, to insure that it is sufficient to allow the machine to operate without any surfaces striking or rubbing together. This difficulty may occur if the windings project beyond the punchings unnecessarily far. In no case should the machines be started until proper clearances are obtained.

When apparatus is first started it should be brought to speed very slowly and carefully watched to see that everything is correct as the speed increases to normal value. Reliable tachometers, or speed indicating devices should be used in starting to prevent a dangerous increase of speed. Oil rings must be examined at slow speed to see if they are carrying sufficient oil to the bearings. In the majority of cases, oil rings should turn at ¼ speed, and properly lubricate the bearings.

The balance of the rotating parts should be carefully noted until the machine has reached its normal rated speed. If the apparatus does not run without vibration the matter must be remedied before the test proceeds. Vibration due to the running of the machine may indicate lack of balance, whereas it may be really due to improper alignment, or to springing of the shaft. When unbalancing occurs in operating machines running above 1200 r.p.m., correction must be made by dynamic balancing. This method will be described later.

Saturation

In order to ascertain the characteristics of the magnetic circuit, a test known as "saturation" is made. The characteristic curve may be obtained by any of the following methods: "generator saturation," "motor saturation," and "ballistic saturation."

The test usually made is "generator saturation." To obtain a saturation curve by this method, the machine is driven as a generator, preferably at constant speed. If, however, a set of readings is known for one speed, they can be obtained for any other by direct proportion. Hence a saturation curve taken at any constant speed at once gives the saturation curve at any other speed. On direct current machines the brushes should always be set on the neutral point when taking a no-load saturation.

In taking a saturation curve on polyphase alternating current generators, a reading of the voltage across each phase must be taken at normal field current, to ascertain if the phases are properly balanced. If they do not balance, an error in the armature is indicated, which must be corrected. On rotary converters careful readings should be taken of the direct current voltage, as well as the alternating current voltage between all phases, with the field excitation giving normal voltage. The phase voltages must be also closely balanced.

Generator Saturation

The usual method of taking a generator saturation curve is to hold the speed constant and increase the field current step by step until at least 125 per cent. of the normal voltage of the machine is reached, taking simultaneous readings at each step of volts armature, volts field, and amperes field. After reaching the maximum value of the field current, without opening the field reduce the current gradually in four or five steps, again taking readings to determine the value of the residual magnetism at various points along the curve. Special care should be taken to insure accurate readings at and above normal voltage, since with alternating current generators, this is the portion of the curve used for calculating the regulation under load. Whenever saturation curves are taken, a record of the air gap from iron to iron should be made upon the record sheet. The length and circumference of spools should also be entered, together with the armature and field specifications.

Motor Saturation

When it is inconvenient or impossible to drive the machine as a generator, a motor saturation may be made. In this case the machine is operated as a free running motor.

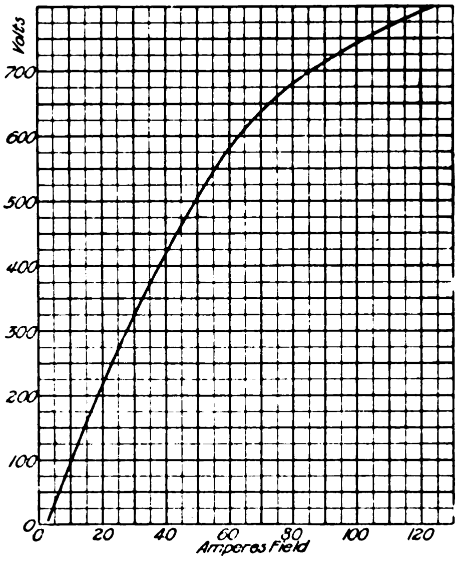


Fig. 4. Saturation Curve on a 500 Kw., 600 Volt, 20 Pole, 360 R.P.M., 3-Phase 60 Cycle A.C. Generator

The driving power must be furnished from a variable voltage circuit. A certain voltage is impressed upon the armature, and the motor field weakened or increased in the case of direct current machines until normal speed is obtained, when a record is made of the volts armature, amperes armature, amperes field, volts field, and speed. The starting voltage should be at least 50 per cent. lower than the normal voltage of the apparatus. The applied voltage at the armature should be increased by steps to 25 per cent. above normal value, and the field increased correspondingly to keep the speed constant; the same readings being recorded at the various steps as before. Readings should also be taken at three or four points as the impressed voltage and field current are lowered to approximately the value at the beginning of the test.

TABLE I—SATURATION

Volts Arm.	Volts Field	Amps. Field	Speed R.P.M.
192	25	18.0	360
228	29	21.0	360
253	32	23.2	360
304	38	29.0	360
416	52	40.0	360
495	62	48.9	360
542	70	55.1	360
579	75	59.8	360
597 597 597	79	62.0	360
614	83	65.4	360
707	110	87.5	360
785	146	117.0	360
755	130	102.0	360
555	74	55.5	360
453	57	43.6	360
287	35	26.3	360
178	26	16.1	360

When testing direct current apparatus in the above manner care should be taken to see that excessive speeds do not result from unstable electrical conditions, and the circuit breaker controlling the motor should therefore be so arranged that it can be readily operated by the tester reading the speed.

On alternating current apparatus, the machine is run as a motor and the impressed voltage varied as already described. The speed is independent of the motor field in this case, and instead of regulating the motor field for speed, it should be regulated to give minimum input current at each voltage. Readings should be taken of voltage impressed, amperes armature, amperes field, and volts field. With induction motors it is only necessary to impress variable voltages at constant frequency and record readings of volts armature, impressed amperes armature, and speed.

The calculation of saturation tests is very simple, as it only consists of applying instrument correction factors and ratios, and plotting upon coördinate paper, volts armature as ordinates and amperes field as abscissæ. Fig. 4, which is plotted from the values given in Table I, shows the results of a saturation test made by one of the above methods.

Ballistic Saturation

In order to make a generator or motor saturation test, the machine must run at, or near, its normal speed. Sometimes it is desirable to test for saturation without the delay and expense of setting up and operating the machine. In this case a test known as "ballistic saturation" can be used, obtained as follows:

First, a machine of given armature winding, armature core, and field structure is operated for a running saturation test as already described. The machine is then shut down and its brushes shifted 90 electrical degrees from their no-load neutral position when the machine was running. The shunt field of the machine is wired to a source of excitation and provided with a field reversing switch so that the field circuit may be quickly opened and reversed. This permits of the field current being interrupted at any value, quickly reversed, and allowed to rise to the same value again. Leads from a ballistic galvanometer are then connected to the armature directly under the center of the brushes of two adjacent studs, all other brushes being removed. The galvanometer circuit should have a resistance such that the voltage induced in the armature, when the field is broken at a maximum current value and reversed, is just sufficient to give the maximum scale deflection on the ballistic galvanometer.

A ballistic curve may then be obtained, from which the running saturation curve can be readily derived. Galvanometer readings are taken at a number of field current values, as in the running saturation tests. The magnetic flux due to each current value is proportional to the induced voltage in the armature when the field is broken and reversed by means of the reversing switch. Hence, if the galvanometer deflections are plotted with the field current, with the former as ordinates, a curve similar to the running saturation curve will be obtained. This curve bears a definite relation to the running saturation curve, depending upon the armature windings, leakage coefficient, galvanometer constant and resistance of the galvanometer circuit. Before taking galvanometer readings at a given field current value, the field current should be reversed one or more times in order to obtain the same magnetic conditions as were obtained in the running saturation curve. Unless this precaution is observed, the saturation curve derived will not agree closely with the running saturation test of the same machine.

The running saturation for any machine may be calculated from the machine constants and this test, without further information. Such a calculation is, however, somewhat involved, and uncertain. It is best to take the ratio of the galvanometer deflection for a given field current, to the armature voltage generated when the machine is running at normal speed with the same field current for excitation. This ratio will hold with sufficient accuracy for all practical purposes throughout the ballistic test, and hence allows of a ready determination of a running saturation curve being obtained on any machine which is a duplicate as regards armature winding and core, and field structure. This method may be used to great advantage to check up individual standard machines and insure that the magnetic circuit and windings are correct. Similar machines should be tested with the same galvanometer and resistance values.

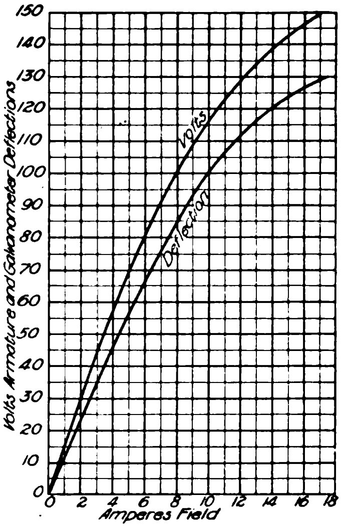


Fig. 5. Ballistic and Running Saturation on a 75 Kw., 125 Volt 6 Pole, 375 R.P.M. Compound Wound D.C. Generator

To obtain the ballistic curve, the armature need only be wedged central with the field bore by wooden or composition wedges to obtain a uniform air gap. Fig. 5 shows the results of a ballistic test and running saturation test, plotted on the same sheet.

(To be Continued)

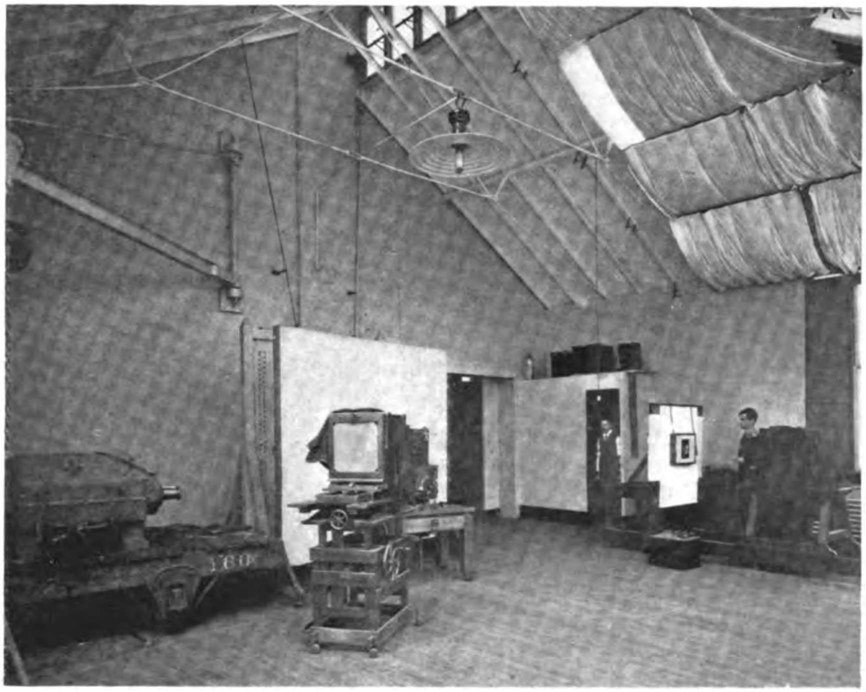
THE PHOTOGRAPH DEPARTMENT

By Martin P. Rice

Manager Publication Bureau, General Electric Company

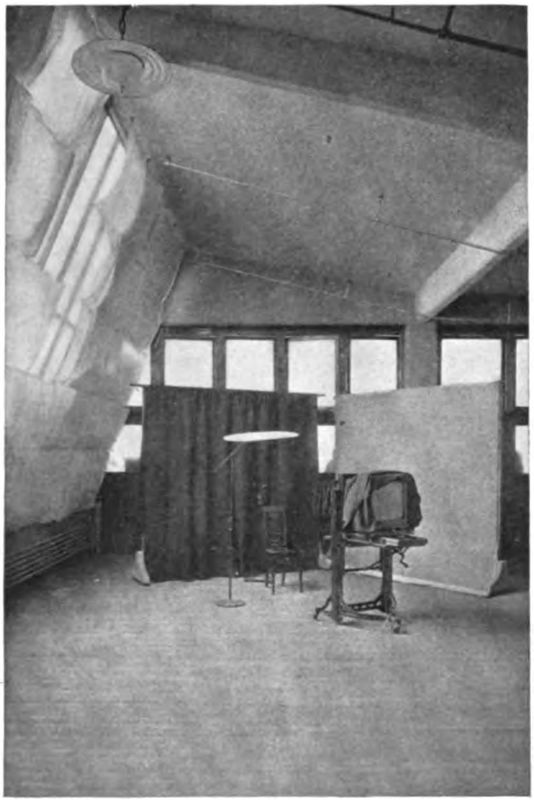
A Photograph Department is a valuable requisite in the manufacturing and commercial organizations of a large plant. Its real value and the wide scope of its work are probably not generally understood. Everyone knows that selling agents use photographs extensively to represent their goods to prospective customers, and the use of photographs in preparing cuts for catalogs and advertising is also well known, but the important employment of photographs as records of tests, as evidence in patent or other litigation, as contract specifications, and as showing the progress of new buildings, is not so generally understood. The General Electric Company has always maintained a well equipped Photograph Department and has recently completed a new concrete building for the principal workshop of the department at the Schenectady Works. Branches of the department are located at the Company's Works in Lynn and Pittsfield, Mass.

The photographic work for one week usually includes the making of about 100 negatives, 500 silver prints, 2000 blue prints and a number of lantern slides and enlargements. The standard negative is 8 by 10 inches, although 11 by 14 inches is employed where the amount of detail makes the larger plate preferable.



General Operating Room

As to subjects, photographs are made to represent every new line of apparatus or



Studio

supplies produced by the factories, and also every special appliance which embodies new features of any description. The large machines are photographed in the shops as they are assembled for testing, and smaller apparatus is transferred to the photograph house. The narrow gauge track connecting all factories enables such transfers to be readily made, and the turntable in the photograph studio facilitates picture making without the necessity of removing apparatus from the car.

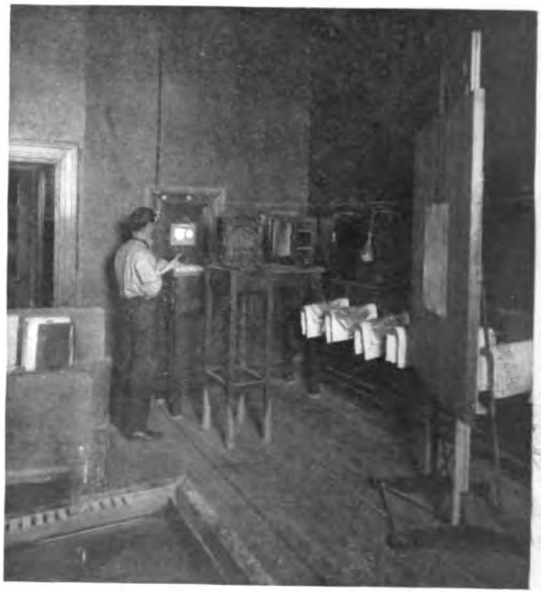
In addition to photographs of individual machines, appliances and their parts, pictures are made of important tests, such as the street car fender tests recently conducted by the New York State Commission. Important drawings and sketches are photographed, as well as changes in plant arrangement, such as the erection of new buildings. A series of photographs in the latter case will often decide a point which might otherwise cause a disagreement between the contractor and the Works' [illegible]

On the second floor of the photograph building, previously referred to, another studio is provided for work requiring extra time and care in arrangement. Here models are posed for pictures illustrating the use of the General Electric Company's household appliances, such as sewing machine motors, coffee percolators, toasters, chafing dishes, radiators, etc.

Under special applications of photography may be mentioned the use of photographic films in the oscillograph, an instrument which records faithfully the almost instantaneous phenomena occurring during electrical tests, in somewhat the same way that a recording pressure gauge makes a graphic record of boiler pressure.

Photographic records are also of value in connection with the microscope and spectroscope. An example of such application is found in the study of the structure of materials and in the investigation of the quality of light from various lamps.

In photographing mechanical appliances, careful preparation is desirable. The camera is charitable toward some faults, but intensifies others. Painted surfaces must be smooth and clean, polished parts must be dulled by touching with putty to prevent confusing reflections and exaggerated high lights. Retouching on a photographic print may produce marvellous changes, but the



Enlargement and Lantern Slide Room

finished picture will never look so real as one that requires no retouching. Therefore, it is well worth while to prepare the subject carefully before making the negative. A negative may frequently be made in the studio where time is available for suitable preparation and where the light may be carefully arranged to secure the best results, but more often the photographer is called upon to photograph machinery or apparatus which has just been tested and is urgently wanted by the customer. Under these conditions, the photographer must do the best he can in the short time available.

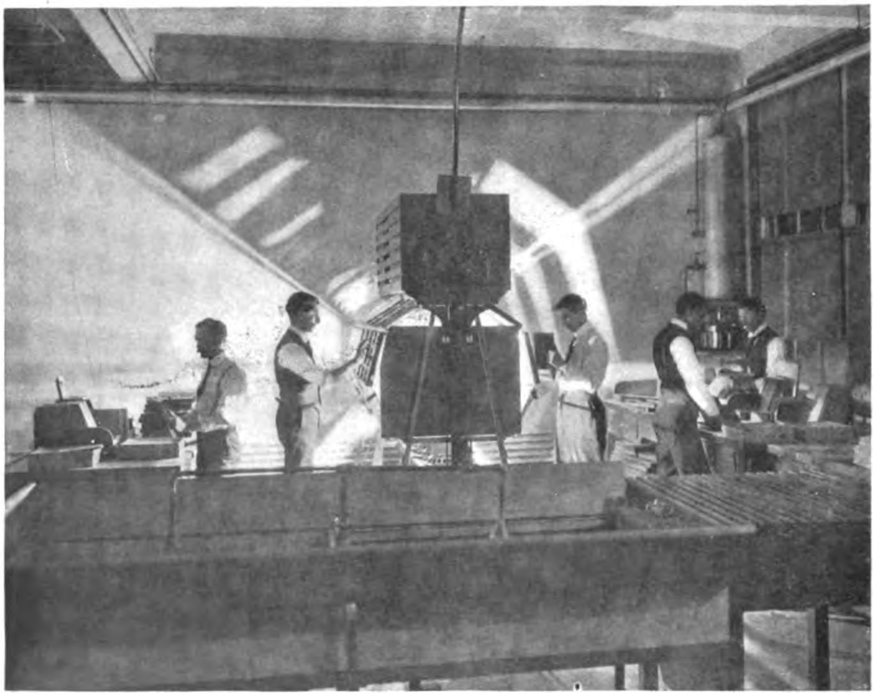
There is no economy in limiting the photographer to insufficient equipment. The varying conditions existing in factory buildings demand lenses of focal lengths varying from 6 to 20 inches, and a series of lenses covering this range is an essential part of the equipment. The first requisite of the studio camera is stability, and the portable camera should be just as rigid as it can be made. Nearly all mechanical photographs require perfectly sharp images, and therefore a depth of focus which, however, is not compatible with speed. If speed is required, depth of focus will generally have to be sacrificed.

In the development of the plate, the usual standard methods are applicable. Several dark rooms are provided in the General Electric Company's gallery so that two or more plates can be developed simultaneously without interference. Separate rooms are also arranged for making prints. The amount of work justifies this arrangement, which in a smaller plant might not be necessary. The dark rooms have no doors, but may be entered through winding passages which admit no light. Ventilation is maintained by electric fans located in metal pipes leading outside of the building. Electric fans are also employed to dry the negatives.

General Work Room

When the negative is dry, it must be numbered, titled, and filed. The numbers and titles of several negatives are written on the typewriter in black ink. They are then photographed by the wet plate process and transferred to the proper negatives, on which spaces have been prepared to receive them by scraping away the gelatine. This process gives a legible title and is not expensive where negatives are titled in considerable quantities.

As photographs constitute important records, they should be carefully protected from fire, water and dust. In a concrete building, such as the one under description, a special fireproof vault for negatives is not essential, especially if, as in this building, sheet metal filing cases are used. Each negative is placed in a manila paper envelope, marked with the negative number and the date. As this information is important, particularly in patent suits, it is also recorded in the photograph house ledger, together with the name of the photographer. The 50,000 or more negatives on file in the General Electric Company's gallery give an almost invaluable pictorial history of the development of the electrical industry.



Blue Print Department

Negatives are utilized for making blue prints, silver prints of various kinds, enlargements for framing, and lantern slides. Blue prints are inexpensive and may be made rapidly in frames equipped with electric arc lamps. The current of warm air ascending from these lamps is employed to dry the prints which have been previously washed in sinks the usual way. Unlike silver prints, blue prints always lie flat and therefore serve admirably for binding in engineering reports and in catalogs of parts of machines built in limited numbers. They are also useful in issuing information of various kinds to the agents of the large selling organization.

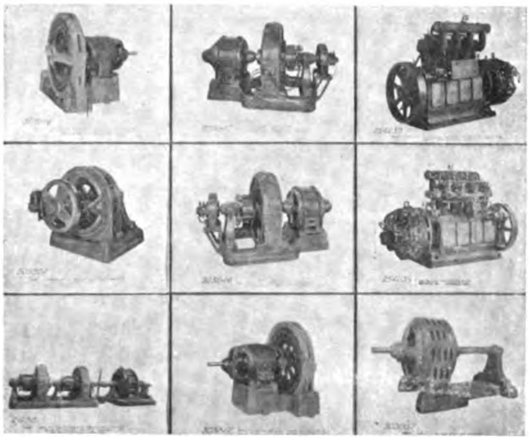
Silver prints can be made with almost equal speed, but are more expensive, due to the cost of developer or toning solution and the higher cost of paper. The mercury arc has been found to be very satisfactory for making prints on developing paper.

For half-tone reproduction, prints on a gelatine coated paper are desirable, because this paper offers a good surface for retouching. These prints may be made by sunlight, or by the arc lamps used in blue printing. Silver prints are usually squeegeed on ferotype plates and dried in an air blast. They are then ready to send out as unmounted prints, or may be mounted on cardboard, cloth, or heavy paper.

The mounting process is facilitated by the use of mounting tissue and electrically heated appliances, which first tack the print at the corners and then heat the entire surface, softening the tissue and pressing the print into close contact with the mount.

Photographs mounted on cloth and collected in books enable an agent to exhibit a complete line of machines or apparatus much more impressively than could be done with merely a printed catalog. The photographs are fastened into a binder on the loose leaf plan and may thus be readily revised as often as may be necessary.

A special dark room is equipped for making enlargements and another for making lantern slides. The enlargements include views of the Works and the most important machines manufactured from time to time. They are usually framed and furnished to technical schools and important customers. Lantern slides are prepared for schools and colleges and for illustrating lectures before technical societies. They include views of machinery, apparatus and supplies. While the subjects are generally the most modern products of the various factories, they also include machines of early types, so that the development of the art may be traced through its various stages. A great deal of information can be given in lantern slides showing thorough methods of manufacture, various lines of machines, and the application of electricity to the generation and distribution of light and power. This branch of photography is educational, and, while as advertising it is indirect, it is not on this account less important.



Photographs Reproduced in Miniature for various Departments

Showing use of Photography for Advertising

The work of the Photograph House could not be carried on satisfactorily without an efficient system for handling the clerical work. All orders for photographs must be stamped to show the date of receipt and turned over to the proper operator with instructions as to precedence. Files are kept showing work in progress and on order, and the system which prevails for following up the work is similar to that in any other form of factory production. Each week the Photograph House submits a report showing work on hand from previous week, orders received during the week, total work completed, and balance carried over to the following week. A glance at this report shows to what extent the production of photographic work keeps pace with the Company's requirements; that is, it shows the output for the week in new negatives, prints, enlargements and lantern slides, and those still on order.

THE TITANIUM ARC[*]

By Wm. S. Weedon

Many years ago a series of experiments was started in order to determine which substance, among the materials available, would give the maximum light efficiency when used as arc electrodes. The work covered a large number of elements, compounds and mixtures, with considerable variation in the method of preliminary treatment.

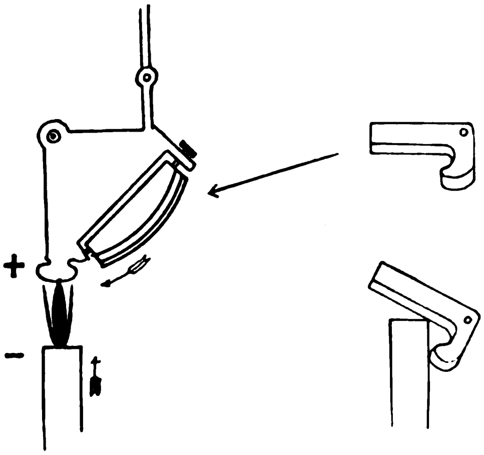


Fig. 1.

Among the substances that were tried there was none which gave as high efficiency in candle-power per watt, as material which contained the element titanium. Of these materials, the carbide of titanium can be obtained in the market in several forms, and as this is probably the most convenient and important material dealt with in this line of work, these should be given.

1. Carbide containing more carbon than is necessary to form the combination TiC, in which the excess of carbon is in the form of graphite.
2. Carbide containing only as much carbon as is necessary to form the carbide TiC, or less than this amount, the latter kind being in all probability a mixture of the carbide TiC and metallic titanium, a small amount of iron also being present.
3. Carbide containing a rather low percentage of carbon and a fairly high percentage of iron.

In the early stages of the experiments the second class of material seemed to be the most satisfactory, while the third class gives an arc which possesses certain objectionable characteristics. In particular the presence of iron seems to cause unsteadiness. As is well known, metallic arcs are far from steady under ordinary circumstances, and in this case the iron seems to accentuate the tendency to unsteadiness.

Characteristics of the Titanium Arc: Direct Current

The arc, as obtained from the carbide, possesses an extremely luminous inner path, while little light is given by the outer mantle and none whatever by the craters. To give the best results the titanium carbide electrode should be the cathode and placed below an anode of copper, the latter being inactive and not wasting appreciably. The light is almost pure white, only the faintest tinge of yellow being noticed when observed from a distance.

After running for some time, there is deposited a "button" of titanium oxide on the copper anode, which causes unsteadiness at times. The phenomenon known as "hissing" or "positive blow" occurs occasionally, resulting in the production of a peculiar jet of flame from the anode, a consequent variation in light intensity, and a decrease in voltage across the arc. This was discussed in a previous paper, from a theoretical standpoint.[†] Further, another difficulty is caused

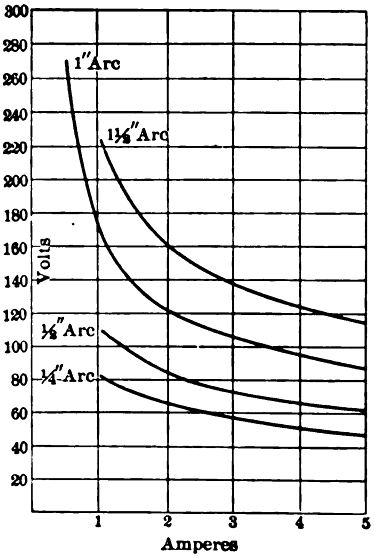


Fig. 2.

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[*] A paper to be presented at the Sixteenth General Meeting of the American Electrochemical Society, in New York City, Oct. 29-30, 1909. Published by permission.

[†] Trans. Am. Electrochemical Soc. (1904), Vol. V., p. 171.

by the formation of an oxide layer on the surface of the titanium carbide electrode. It will be seen that this leads to complications in starting the arc after it has been extinguished for a short time, since the oxide is non-conducting.

The button on the anode does not offer serious difficulty, since a device by Mr. Halverson, designed for the magnetite lamp, ercomes this obstacle. The device referred to is an anode "rocker" connected with the lamp mechanism, so that the arc plays upon one portion of the anode while running, but strikes from another portion. By adapting this idea of the rocker anode, it has been found possible to strike the arc, even though the cathode and anode both have non-conducting surfaces. The starter and method of operation are shown in Fig. 1.

It will be seen that the arc is struck from the side of the lower electrode just below the tip, and after the current is established the electrodes return to running position, the arc running along the anode and climbing the cathode until it also is in normal position.

The titanium arc is a flame arc, and the efficiency increases with increase in current density and with increase in arc length. The volt ampere curves are given in Fig. 2, and the volt arc length curves in Fig. 3. The power consumption curves, shown in Figs. 4 and 5, indicate that we have here a very efficient arc. At 3 amperes, 103 volts and 1 inch arc length, we have only 0.228 watts per horizontal candle-power. The mean spherical candle-power at 2.87 amperes, 95 volts (273 watts), is 535, and the mean mispherical candle-power 737.6. On this s the power consumption is 0.51 watts mean spherical candle-power and 0.37 watts per mean hemispherical candle-power; this corresponds to an efficiency of 1.96 mean spherical candle-power, or 2.70 mean hemispherical candle-power per watt.

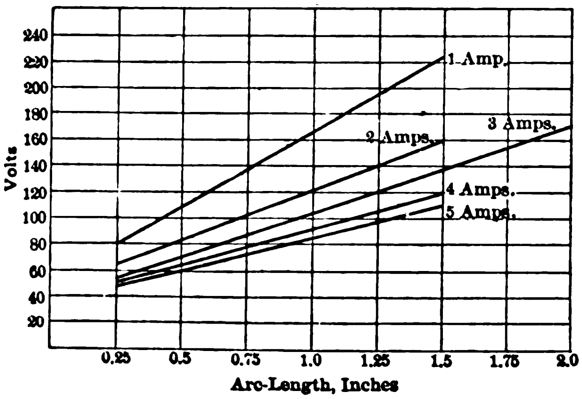


Fig. 3

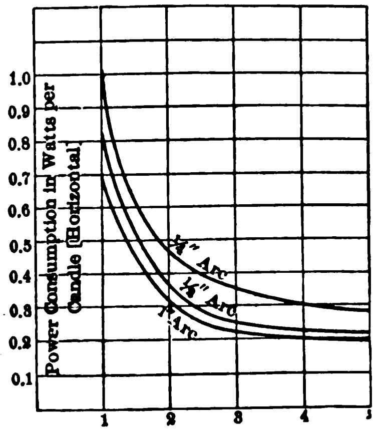


Fig. 4

The electrical measurements given were made at the arc terminals, and the photometric measurements were made through a clear glass globe of the usual thickness.

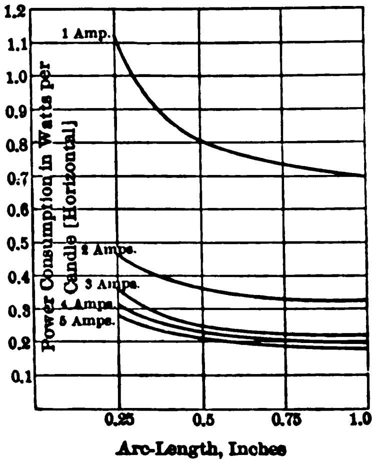


Fig. 5

A study of the efficiency curves will show that titanium carbide arcs are most satisfactorily operated on a constant current circuit rather than on a low voltage multiple circuit (with the necessarily short arc length).

Some photographs have been taken in order to give a comparison of the various arcs. Since these were taken through the globe, the reflection of the flame is sometimes reproduced in the photographs, and should not be confused with the arc itself.

Fig. 6 shows the plain carbon arc. Note the absence of light in the arc stream, while the terminals are very luminous.

Fig. 7 shows the arc obtained from Conradty's flame carbons. The arc stream is luminous as well as the terminals, but there is an entire lack of structure in the flame.

Fig. 8. Magnetite as cathode and copper as anode. Arc length 1 inch, current 3 amperes. No light is given off by the terminals, and all comes from the path of the arc. Structure shown clearly, the inner path giving a large portion of the light, but the outer mantle also luminous.

Fig. 9. The titanium arc. Lower electrode (cathode) titanium carbide. Upper electrode copper. Arc length 1 inch, current 3 amperes. Structure very clearly defined, inner path giving nearly all the light.

Fig. 10. Same as Fig. 9, but showing tendency for the outer mantle to form in layers. This occurs occasionally, and does not interfere with the steadiness of the arc.

Fig. 11. Titanium arc, flickering due to air currents. This arc is very sensitive, and the air currents must be controlled carefully by suitable draft arrangements.

Fig. 12. This shows the tendency of the titanium arc to "crawl" up the side of the anode, owing to air currents or improper centering of electrodes.

Fig. 13. The titanium arc is also sensitive to irregularities in the composition of the electrode. In this photograph a dark space is observed around the anode, and this causes flickering. The titanium used contained iron.

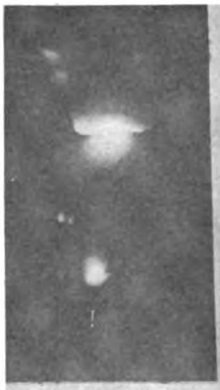


Fig. 6.

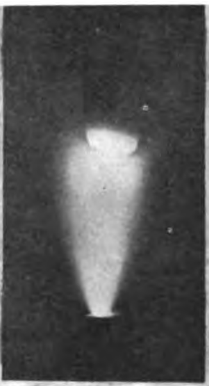
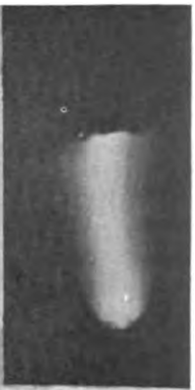


Fig. 7.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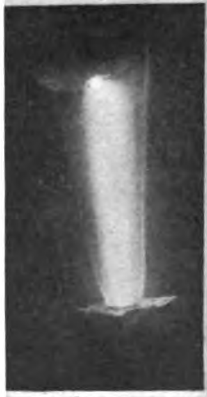
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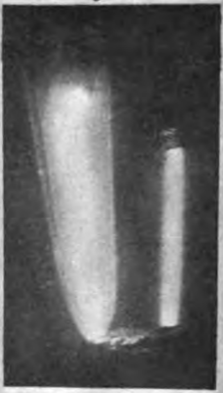
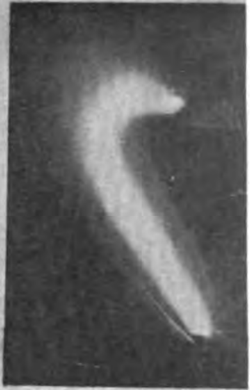


Fig. 10.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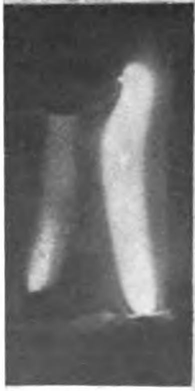
Fig. 12.

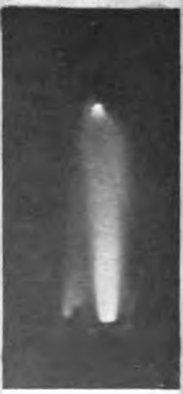
Fig. 13.

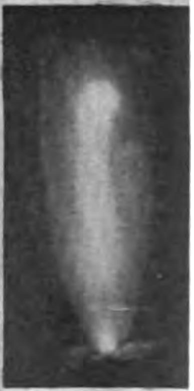
Fig. 14.

Fig. 14. This photograph is not very clear, owing to the confusion caused by the reflection in the globe. It represents the tendency to darken around the cathode, and this seems to be due to the presence of some impurity

of grain handling apparatus induction motors have advantages that render them superior to any other form of drive.

It is evident that by using an individual motor, either direct connected, belted, or provided with a relatively short rope drive, for each elevator leg, conveyor, car puller or exhaust fan, the friction loss which is inevitable where long lines of shafting or long rope or belt connections are necessary, is to a very large extent done away with, and that the total horse-power required for a given amount of work is greatly reduced. Due to the fact that the modern induction motor is an extremely simple device, consisting of a stator and a practically indestructible rotating element, it requires no expert attention, and when once started will operate continuously at a uniform speed. If the power is received from a central station, the expense of engineers, firemen, etc., is altogether eliminated, and the cost of operation is directly proportional to the amount of work performed and ceases the moment the motor is stopped. The polyphase induction motor, which is recommended for work of this kind, has no commutator, and as a consequence there is no sparking to be provided against.

The matter of determining the amount of power required for driving grain elevators with induction motors involves a simple mathematical problem: given the height to which the grain is to be elevated and the bushels capacity per minute, the foot-pounds per minute required to elevate this quantity can be readily calculated. To this result it is necessary to add, of course, a certain percentage to cover the friction loss caused by the belt or rope connections, this percentage varying with the form of connection used between the motor and the elevator leg, conveyor, or exhaust fan. Even under the most unfavorable conditions, however, this friction loss with motor drive will be far less than that which results from driving the various units from a single source of power through long lines of shafting or by other mechanical means of transmission.

The simplicity, compactness, and relatively light weight of the polyphase induction motor render it unnecessary to provide special foundations for the sizes usually employed in grain elevators.

In some instances where motors are used to operate car pullers or conveyors, space economy may be an important factor, and the fact that the induction motor can be installed on the floor, wall or ceiling, should be taken into account when providing for the adoption of motor drive.

If a motor is required to operate where there is considerable dust in the air, special dust-proof bearings can be provided; but under the conditions ordinarily prevailing in modern grain elevators, this is not necessary and the standard motors manufactured by the General Electric Company will answer all requirements, provided they are cleaned occasionally and the oil in the bearings renewed. The use of the induction motor for this work not only reduces the friction loss, but curtails to a large extent the expense involved in the first cost of shafting and belting, at the same time minimizing the labor cost of maintenance, replacements and repairs, and effecting a cleanliness and safety in operation not otherwise obtainable.

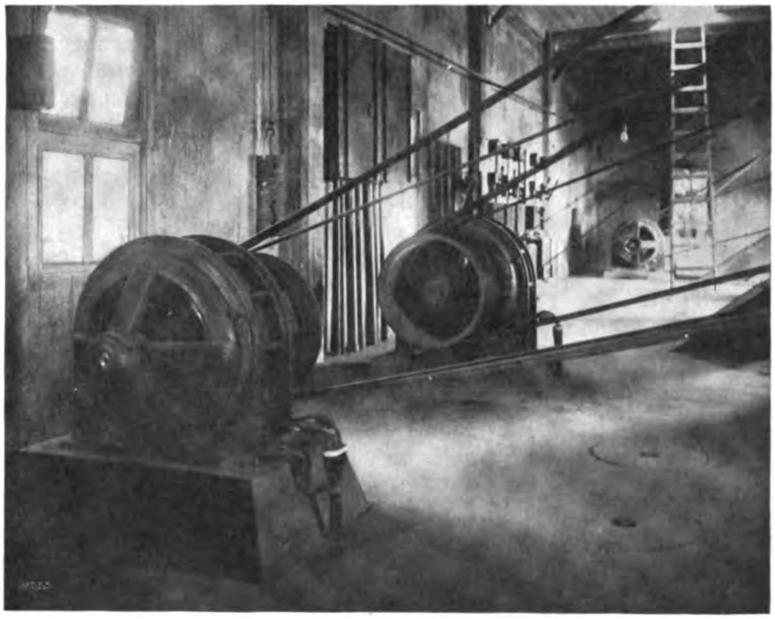

Fig. 1. Induction Motors Driving Elevator Legs. Washburn Crosby Company

In erecting new elevators, the adoption of electric drive will frequently affect the cost of building construction, as the supports necessary for heavy line shafting, hangers, pulleys, etc., need not be provided where induction motors, with their relatively short belt or rope connections, are used. Where the motor is direct connected this expense is entirely eliminated. In many cases, this saving will amount to about five per cent. of the total cost of the building.

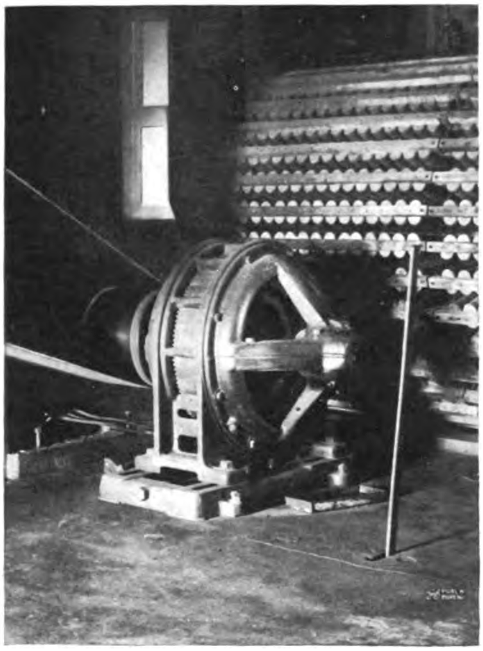

Fig. 2. 10 H.P. Induction Motor Driving Separators and Screw Conveyors. Washburn Crosby Company

The only valid objection which has heretofore existed to the operation of elevator legs by induction motors, has been the liability of the leg to run backward when the power was shut off from the motor, due to the weight of the grain. This back legging or forming of a "choke," is now rendered impossible by the use of an attachment which permits the motor to run only in one direction; the instant it is stopped, a powerful friction clutch holds the leg stationary. In order that the elevator may start on full load, motors for driving this apparatus are generally provided with a friction clutch which is thrown in after the motors have attained full speed.

While theoretically the best method of operating grain handling machinery is to use individual motor drive throughout, the practice in most of the grain elevators which have adopted electric drive has been to combine the individual and group systems. Ordinarily, induction motors are supplied for each elevator leg, car puller, and exhaust fan, while the cleaning machinery, such as separators, screw conveyors, dust collectors, etc., is generally driven in groups by single motors. This system of group drive has much to recommend it, especially in cases where the machinery is compactly grouped, and where the various operations are interdependent. The motors may be controlled either directly at the point of operation,—in which case small panels with starting compensators are provided for each motor,—or the control of all the motors may be centered at some distant point.

Since the year 1870, when the forerunner of the present roller process of flour production was introduced into the United States from Hungary, numerous improvements have been made tending toward the simplification of the original process and the increase of its mechanical efficiency, until at the present time the typical commercial flour mill of the United States is equipped with milling machinery that is a fitting monument to American mechanical genius. Practically all operations which formerly employed manual labor have been eliminated, and every process of flour production, from the time the grain is received until the finished product is ready for shipment, is carried on automatically.

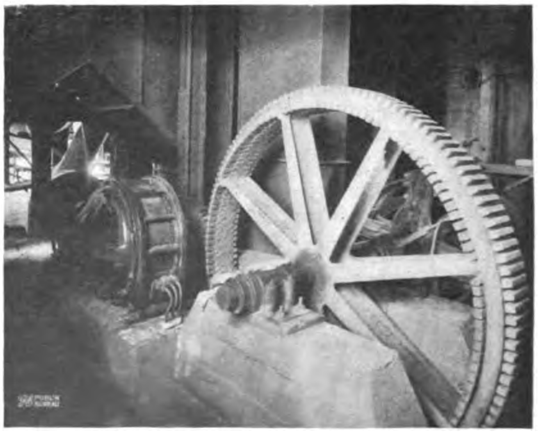

Fig. 3. 50 H.P. Induction Motor Driving Belt Conveyor. Washburn Crosby Company

In the modern flour mill the several milling processes are interdependent, and it is therefore necessary that the different sections of the machinery should move as a unit, the required variations in the speeds of the individual machines being attained by means of belts or gears. In order to accomplish this result, the use of an immense amount of shafting and belting is unavoidable, and notwithstanding the fact that the men who perfected the present milling machinery used every endeavor to reduce the friction loss to a minimum. In most of the commercial mills great care is taken to obtain as nearly as possible a perfect alignment of the shafting; to secure proper lubrication, and to largely reduce the friction loss in the bearings by the liberal use of roller or ball bearings. Under these conditions it is evident that the amount of friction loss which can be eliminated by the adoption of motor drive is far less in the milling process than in the grain handling end of the industry.

In spite of these conditions, however, the use of motor drive has many positive advantages; without inconvenience, the motor or motors can be located in the mill close to the machinery and apply their power centrally on the main shaft; the length of shafting and belting being thereby reduced. The speed is constant, and when the motor is connected with a reliable source of power, there is entire freedom from interrupted service.

The writer recently visited a flour mill in which a single 400 h.p. General Electric induction motor was used to drive the entire milling equipment. This motor has been running for more than five years, giving the usual 24 hour service, and has not as yet caused a single shut-down.

Where a mill contains several groups of machinery it will usually be found advisable to install a separate motor for each group, and where additions are made to the mill the new machinery can be set up and connected to its own motor without in any way interfering with the operation of the original equipment.

The perfection attained in the construction of the modern induction motor and its ability to maintain constant speed even under heavy overloads, render it theoretically possible to economize in power by driving the various sections of the milling machinery by means of individual motors; but the writer knows of no installation where this has been attempted.

Prior to 1820 the flour mill machinery of the United States was driven by animal power wind mills or water wheels. In that year steam was first utilized for this work, and in spite of numerous exceptions it is the predominant source of power in the industry today.

In changing over a mill or elevator from mechanical to electrical drive the practical operator has to consider whether it will be true economy to discard the existing power plant and take current from a central station, or to utilize the engine equipment already installed for driving generators.

Where new mills are constructed it is usually advisable to take power from central stations, as they can generally grant low rates for this service, due to the steady demand on their equipment. In this way the mill operator avoids the first cost of power house and machinery, the expense of maintenance and supervision, and the interest and depreciation charges.

The up-to-date central station is provided with reserve machines, and the possibility of interrupted service, such as might occur by reason of the failure of a generator in an isolated plant, is thereby reduced to a minimum. That these factors are fully appreciated by mill men, is indicated by the fact that among the flour mills and grain elevators of Minnesota, about 70 per cent. of those electrically operated are using central station power.

To meet the conditions existing in mills and elevators of large capacity, which are provided with modern reciprocating engines and are so situated that central station current is not available, a complete line of apparatus suitable for isolated plants has been developed; the generators being designed to operate at the usual engine speeds.

For prime movers in new plants so located, the use of Curtis steam turbines is recommended, and compact turbine-generator sets will insure economy in both steam consumption and required floor space.

In isolated plants equipped with reciprocating steam engines, the power developed may be greatly increased without adding to the boiler equipment, by using low pressure Curtis steam turbines in combination with the engines. The turbines render possible the utilization of all the available energy incident to the use of high vacuum, and take the steam directly from the exhaust pipes of the reciprocating engines without valves or other governing mechanism.

The adoption of electric drive for grain elevators and flour mills is steadily progressing in spite of the many improvements made in the various prime movers used for mechanical drive, principally because of the fact that the simplicity and high efficiency of the induction motor insures the closest possible approximation to the direct application of the total initial power developed.

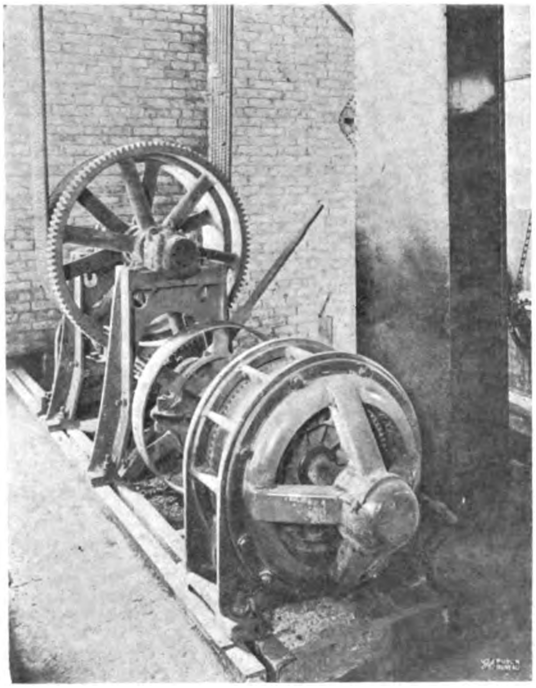

Fig. 4. Induction Motor Driving Elevator Legs through Friction Clutch and Back Gear Device. Northwestern Consolidated Milling Company

DESCRIPTION OF TWO INSTALLATIONS

By L. O. Gordon

The Washburn-Crosby Company

The Washburn-Crosby Company, of Minneapolis, Minn., is one of the largest flour mills in the world, and has a capacity of 35,000 barrels of flour per day of 24 hours. Within the past two years, the Company has erected an immense elevator capable of storing 750,000 bushels of grain: it is constructed of reinforced concrete, has 15 circular bins, each of a capacity of 50,000 bushels, and is thoroughly modern in every respect.

The elevator is not used for storage purposes, however, but merely for handling the wheat as it is brought in for milling. The average amount of wheat handled per day is about 100,000 bushels.

The management appreciated the advantages to be derived from the use of induction motors in a building of this kind, for operating the various elevator legs, screw conveyors, ventilating fans, etc., and installed twelve motors for the work, with a total capacity of 665 h.p. For unloading the cars six pairs of Clark grain shovels are employed, each pair being able to handle 1000 barrels in about 15 minutes. These shovels are operated from a line shaft driven by a 50 h.p., 900 r.p.m., form K motor.

The car puller, which is of the three drum type, is geared to a 50 h.p., 900 r.p.m., form K motor, and will haul eight or nine loaded cars at a speed of 50 ft. per minute.

These motors are all General Electric three-phase, 60 cycle standard machines, wound for a 440 volt circuit, each motor being furnished with a standard induction motor panel, including oil switch, ammeter and compensator. There are six elevator legs in the building, all of which are used for receiving purposes only. Four of these legs are operated by 75 h.p., 720 r.p.m. motors, and the remaining two by 35 h.p., 900 r.p.m. motors. These motors, with their individual controlling panels, are shown in Fig. 1.

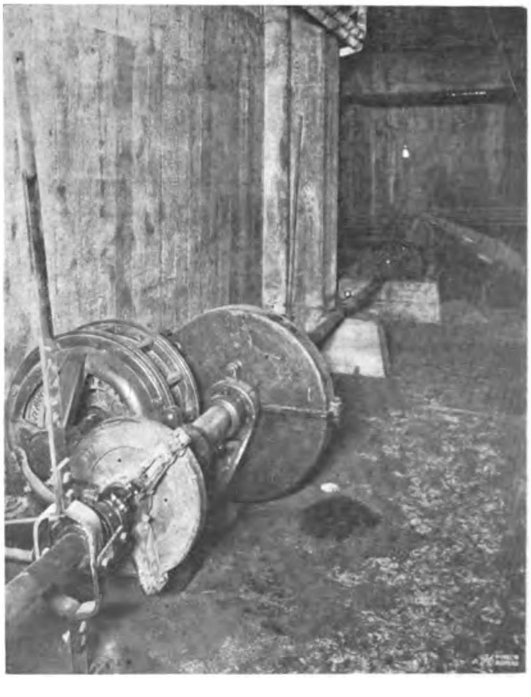

Fig. 5. Back Geared Induction Motor Driving Two Conveyor Belts. Northwestern Consolidated Milling Company

Of the four larger legs, three have a capacity of 10,000 bu. each per hour, elevating the grain to a height of 212 feet by means of a 30 in. belt; while the fourth has a capacity of 12,000 bu. per hour and elevates the grain 158 ft. on a 32 in. belt.

The two smaller legs have capacities of 7000 and 5500 bu. per hour, elevating the grain 212 ft. on a 20 in. belt, and 90 ft. on an 18 in. belt, respectively. The 35 h.p. motor, which operates the larger of these two conveyors, also drives two 18 in. screw conveyors, the length of one being 31 ft., and that of the other 41 ft. The elevator legs are driven by means of ropes passing over large pulleys located at the elevator heads.

A small pulley is placed on two of the motors on the end opposite the sheave pulley, from which is belted a small fan to discharge the dust thrown out by the wheat at the elevator head.

The following machines are driven by a 75 h.p., 700 r.p.m., form K motor belted to a line shaft on the cleaning floor:

1—18 in. screw conveyor 75 ft. long
3—18 in. screw conveyors 10 ft. long
2—Mill separators, each of a capacity of 600 bbls. per hr.
2—Automatic dust collectors
3—Double receiving three-sieve Prince separators, each of a capacity of 6800 bbls. per hr.

The motor which drives this line shaft is shown in Fig. 2.

In addition to the above machines, two mill separators, two automatic dust collectors, and a 12 in. screw conveyor 38 ft. long, are driven from another line shaft belted to a 35 h.p., 900 r.p.m., form K motor.

In the basement, five rubber belts 36 in. wide are employed for distributing purposes; three of these belts being 180 ft. long and two 105 ft. long. These belt conveyors are driven from a line shaft geared to a 35 h.p., 900 r.p.m., form K motor.

Grain is weighed by an automatic weighing machine and conveyed to the mills by a 40 in. rubber belt about 1200 ft. long, having a capacity of 11,500 bbls. per hour. This belt conveyor is operated by a 50 h.p., 900 r.p.m., form K motor, geared to the belt pulley through a friction clutch so arranged that the motor can be brought up to speed without load. Fig. 3 shows this motor, gear and clutch.

Northwestern Consolidated Milling Company

Since the electrical equipment was installed in the above elevator of the Washburn-Crosby Company, the General Electric Company has developed the back gear attachment for induction motors, as exemplified in the equipment of the Northwestern Consolidated Milling Co., of Minneapolis, Minn. The problems previously encountered in the driving of elevator legs were greatly simplified by this device, which rendered possible the elimination of practically all belting by direct connecting the back gear shaft to the apparatus to be driven.

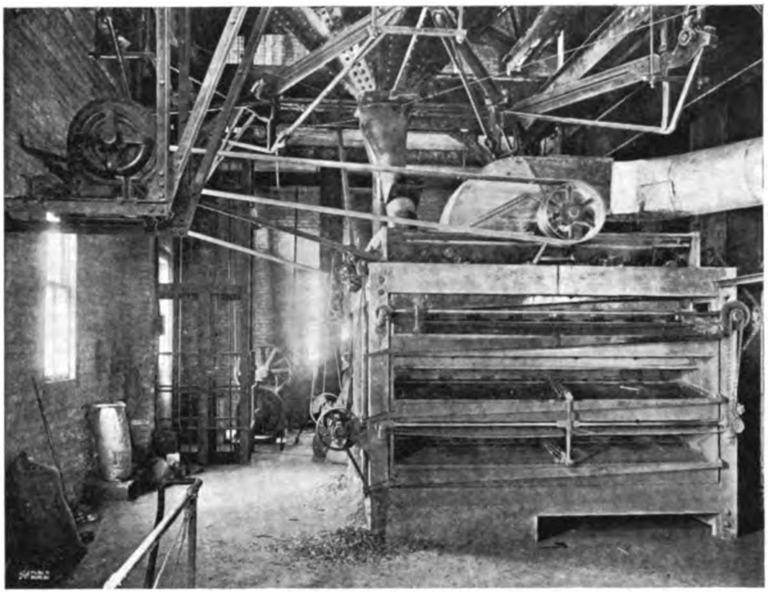

Fig. 6. Induction Motor Driving Cleaner. Northwestern Consolidated Milling Company

The new elevator of the Northwestern Consolidated Milling Company, which has just been completed, is the largest grain elevator in the country, if not in the world, having a capacity of one million bushels. The elevator is built of brick and is operated throughout by General Electric induction motors.

For unloading the grain, four grain shovels are employed, each of which is operated by a 15 h.p. back gear motor. From the cars the wheat is conveyed to the elevator legs by two belt conveyors driven by one 25 h.p. back gear motor. The motors on the legs are 50 h.p., 900 r.p.m. machines, geared through a clutch to an Evans backstop device and to a shaft on which is mounted a sheave pulley with a rope drive. The Evans backstop device is essentially a friction clutch which permits the elevator leg to run in one direction only. Should the electric power supply suddenly fail when grain is being elevated, this clutch automatically sets and prevents the leg from running backwards due to the weight of the grain. The second clutch is an ordinary friction clutch which permits the motor to be started without load. Fig. 5 shows one of these motors with the Evans backstop device in place.

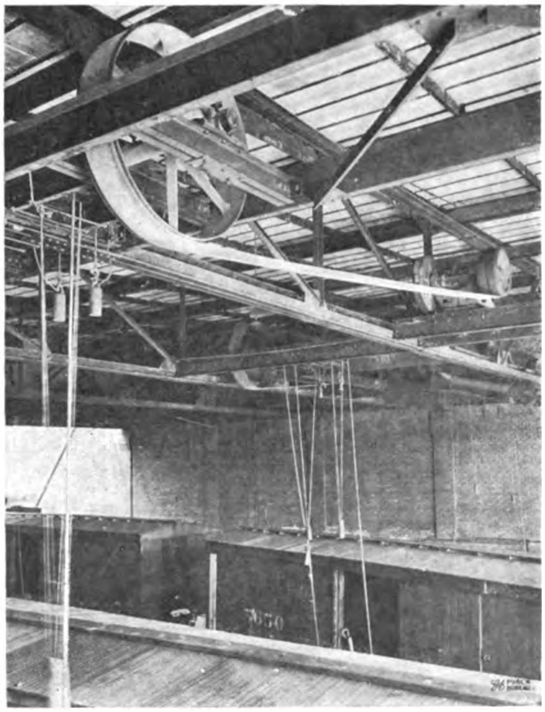

Fig. 7. Car Shovels Operated by Back Geared Induction Motor. Northwestern Consolidated Milling Co.

The receiving separators are belted to 15 h.p. 900 r.p.m. motors, and for transferring grain to the various bins and mills a number of short conveyor belts are used, direct connected to back gear motors.

This elevator is equipped with a very complete dust collecting system, and is practically free from dust. The fan for this system is direct connected to a 35 h.p., 1200 r.p.m. motor.

All of the motors in this elevator are operated from a 750 kw., 480 volt, 2 stage Curtis turbine generator. The entire station equipment consists of this turbine, a 35 kw. turbine exciter set, a 40 kw. motor-generator set, and the switchboard, all of which were furnished by the General Electric Company.

TRANSMISSION LINE CALCULATIONS

PART II

By MILTON W. FRANKLIN

Self Induction

Experiment shows that current i in a straight conductor $A'B$ will exert a force F upon a magnetic pole of strength m, placed at any point A in the field surrounding the conductor (Fig. 3). The force exerted by the current in any line element, $B = dy$, will be

$$dF = k\,\frac{\mu m i}{r^2}\sin\theta\,dy \qquad (1)$$

and will be perpendicular to the plane $A\ A'\ B$ and in the direction of a right hand screw with respect to the current flow.

m is the strength of the magnet,
i is the strength of the current,
μ is the magnetic permeability of the field,
r is the distance $B\ A$,
dy is the length of the line element,
ρ is the distance of A from the line,
k is a constant depending on the units employed.

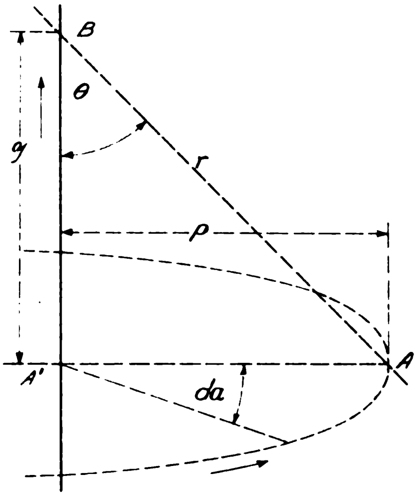

Fig. 3

When the line is of practically infinite length, the numerical value of F is obtained by integrating over the length of the line between the limits $+\infty$ and $-\infty$.

$$F = \int_{-\infty}^{\infty} k\,\frac{\mu m i}{r^2}\sin\theta\,dy \qquad (2)$$

To perform this integration, r and y must be expressed in terms of θ; thus, $r = \rho\csc\theta$, $y = \rho\,ctn\,\theta$ and therefore $dy = -\rho\csc^2\theta\,d\theta$. Also when y approaches ∞, θ approaches $\tan^{-1}\left(\frac{\rho}{\infty}\right)$ and the limits of integration become $\tan^{-1}\left(\frac{\rho}{\infty}\right)$ and

$tan^{-1}\left(\frac{\rho}{-\infty}\right)$. The expression (2) then becomes

$$F = k\mu mi \int_{tan^{-1}\frac{\rho}{-\infty}}^{tan^{-1}\frac{\rho}{\infty}} \frac{-\sin\theta\ \rho\csc^2\theta\ d\theta}{\rho\csc^2\theta}$$

$$= \frac{-k\mu mi}{\rho}\int_{tan^{-1}\frac{\rho}{-\infty}}^{tan^{-1}\frac{\rho}{\infty}} \sin\theta\ d\theta$$

$$= \frac{-k\mu mi}{\rho}\Big[-\cos\theta\Big]_{\pi}^{0} = \frac{2\,k\mu mi}{\rho} \qquad (3)$$

The work done in moving the magnetic pole around the conductor in the circle *rad* $^{-1}\rho$ will be the line integral of F $\rho\, da$ taken over the whole circumference, where $F=\frac{2\,k\mu mi}{\rho}$, and ρda, the element of path thus

$$W = \frac{2\,k\mu mi}{\rho}\int_0^{2\pi}\rho da = 2\,k\mu mi\Big[a\Big]_0^{2\pi} = 4\pi k\mu mi \qquad (4)$$

The work done is thus seen to be independent of the value of ρ, or the distance of the magnetic pole from the conductor.

It is convenient to regard the force as giving rise to lines of magnetic force, or flux, surrounding the conductor, and from the uniformity of the field at any given distance from the axis of the conductor, the lines are found to be circular, coaxial with the conductor and lying in planes perpendicular to the common axis.

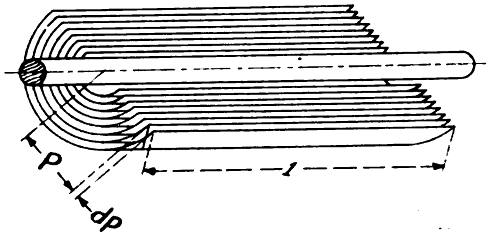

Fig. 4

Assuming that all lines arise from equal forces, it follows that the *strength* of field at any point is indicated by the density of distribution of lines at that point; *i.e.*, the number of lines per unit area of the plane perpendicular to their direction, or passing through their axis.

As work is defined as Force × Distance, and as the distance around the conductor, on the circumference of any coaxial circle, varies *directly* as the radius, it follows that the force on any such circumference must vary *inversely* as the radius, if the work done in taking the magnetic pole around is to be constant.

This condition has been shown above (4) to exist, and it naturally follows that the density of the lines in any coaxial cylinder varies inversely as its distance from the axis.

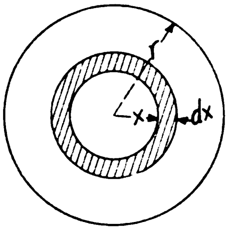

Fig. 5

The field surrounding the conductor may be conveniently regarded as made up of an infinity of coaxial cylindrical shells, each of infinitesimal thickness, and the density of the lines in any shell may be regarded as constant throughout its thickness (Fig. 4).

Taking a cylinder whose radius is ρ, whose thickness is $d\rho$, and whose length is unity, the number of lines in its wall is given by

$$2\,k\,\mu\,i\ \frac{d\rho}{\rho} \qquad (5)$$

where k is a constant depending upon the units employed, i the current in the conductor, and μ the permeability of the substance of the shell, that is, of the field surrounding the conductor. When the current is given in electromagnetic units, and distances in centimeters, the expression for the lines or magnetic flux (5) reduces to

$$d\,\phi = 2\,\mu i\frac{d\rho}{\rho} \qquad (6)$$

The total number of lines or flux surrounding each unit length of conductor outward to the distance R from the axis is the summation of all the lines in every shell from the surface of the conductor to the distance R from the axis. To these must be added the lines within the substance of the conductor.

The lines outside the conductor are given by

$$\phi = 2\,\mu i\int_r^R\frac{d\rho}{\rho} = 2\,\mu i\Big[ln\ \rho\Big]_r^R = 2\,\mu\, ln\left(\frac{R}{r}\right) \qquad (7)$$

where r in the radius of the conductor.

The flux within the substance of the conductor is calculated on the assumption that the current is uniformly distributed within the substance of the conductor. Owing to skin effect, this assumption introduces an error, which, however, is of negligible magnitude in the calculation of transmission lines.

Consider the ring of radius x and thickness dx, within the conductor (Fig. 5). The current in the portion of the conductor within the ring is to the total current in the conductor as

$\pi x^2 : \pi r^2 \therefore i_1 = \frac{\pi x^2}{\pi r^2} i = \frac{x^2}{r^2} i.$ The flux in unit length of the substance of the ring itself is equal to $\left[\text{Force} = \frac{2\mu i}{x}\right] \times \left[\text{Cross-sectional area} = dx\right]$

$$\text{or } d\phi = 2\mu_1 i_1 \frac{dx}{x} = 2\mu_1 i \frac{x^2}{r^2} \frac{dx}{x} \qquad (8)$$

But this flux surrounds only the current within the ring, and its influence on the whole current is therefore equivalent only to a flux proportional to this fraction of the current, hence:

$$\phi_1 = \int_0^r 2\mu_1 i \frac{x^3}{r^4} dx = \tfrac{1}{2}\mu_1 i \qquad (9)$$

where μ_1 is the permeability of the conductor.

The total flux may then be expressed as the sum of these two quantities, thus:

$$\phi = 2\mu\, ln\left(\frac{R}{r}\right) + \frac{\mu_1}{2} i = i\left[2\mu\, ln\left(\frac{R}{r}\right) + \frac{\mu_1}{2}\right] \qquad (10)$$

The quantity within the brackets is a function of μ and μ_1, the permeability of the medium surrounding the conductor and of the conductor itself, respectively. If the conductor is surrounded by air and is composed of copper, aluminum or any other non-magnetic substance, the values of μ and μ_1, become constant and equal to unity (approximately), and the quantity within the brackets reduces to $\left[2\, ln\left(\frac{R}{r}\right) + \tfrac{1}{2}\right]$ (11)

This is obviously a constant for constant values of R and r and may be expressed by the symbol λ.

The expression for the flux then becomes

$$\phi = \lambda i. \qquad (12)$$

When the flux linking a conductor changes in value there is set up in the conductor an e.m.f. which is proportional to the rate of change of the flux. This holds for any change of flux whether due to the influence of external causes or to changes of the current, in the conductor itself, which causes the flux.

The rate of change of flux is $\frac{d\phi}{dt} = \lambda \frac{di}{dt}$ (13)

and the e.m.f. generated is $-e = \lambda \frac{di}{dt}$ *. This is called the e.m.f. of *self-induction* if the change of flux is due to the current in the conductor itself; or the e.m.f. of *mutual induction* if the flux is due to a current in some other conductor situated near the first.

The units thus far employed have been *absolute* or C.G.S. units and natural logarithms. To reduce the results to *practical* units and to common logarithms, recourse is had to the following conversion factors:

1 C.G.S. unit of current = (1.0×10) amp.
1 C.G.S. unit of e.m.f. = (1.0×10^{-8}) volt
1 C.G.S. unit of length (cm) = (6.21370×10^{-6}) mile.
1 C.G.S. unit of length (cm) = (3.28083×10^{-5}) 1000 ft.
Common *log* × 2.302585 = natural *log*. (*ln*)

The units in the ratio $\frac{R}{r}$ do not require to be converted as the same conversion factor would appear in both the numerator and the denominator, and would consequently vanish.

Both quantities must, however, be expressed in the same units.

From (11), the symbol λ now reduces to

$$\left[4.605170\, log\left(\frac{R}{r}\right) + \frac{1}{2}\right]$$

and on substituting $\frac{d}{2}$ for r this expression becomes

$$\left[4.605170\left(log\left(\frac{R}{d}\right) + log\, 2\right) + \frac{1}{2}\right]$$

where d is the diameter of the conductor.

Substituting E = volts, and C = amperes, in equation (14) gives

$$E = \left[4.605170\left(log\left(\frac{R}{d}\right) + log\, 2\right) + \frac{1}{2}\right] 10^{-9} \frac{dC}{dt} \qquad (15)$$

which is the induced e.m.f. in volts per cm. length.

The e.m.f. in volts per mile is given by

$$E_m = \left[7.41133\left(log\frac{R}{d} + log\, 2\right) + .80463\right](10)^{-4} \frac{dC}{dt}$$

which may be further simplified to

---

* The negative sign is due to a convention regarding the direction of the induced e.m.f. which according to Lenz's Law is opposite to that of the current causing the flux. In what follows this sign is omitted as leading to no ambiguity.

$$E_m = \left[7.41133\ log\frac{R}{d} + 3.03566\right]\left(10\right)^{-4}\ \frac{dC}{dt} \qquad (16)$$

The quantity within the brackets is called the *coefficient of self-induction* of the conductor per mile length, and is expressed in terms of a unit called the *henry*, and commonly indicated by the symbol L; whence,

$$L = \left[7.41133 log\left(\frac{R}{d}\right) + 3.03566\right]\left(10\right)^{-4} \text{henries.} \qquad (17)$$

$$\text{From (16), } E = L\frac{dC}{dt} \qquad (18)$$

$$\text{and } \phi = L\,C \qquad (19)$$

When $\frac{dC}{dt}$ is equal to 1, *i.e.*, when the current changes at the rate of one ampere per second, the value of the induced volts becomes equal to the value of the coefficient of self-induction of the conductor; hence, a self-induction of one henry is a self-induction which will cause an induced e.m.f. of one volt with a change of current equal to one ampere per second.

In the case of a transmission line consisting of two parallel conductors, the quantities R and d in (17) become the interaxial distance and the diameter of the conductors respectively, and the equation then gives the coefficient of self-induction per mile of each of the conductors composing the line.

Calculated values of L for various interaxial distances and sizes of wire may be found in Tables 1 and 15 in the July and September issues of the REVIEW.

These tables give the self-induction per wire for a two-wire single-phase line per 1000 feet.

It is obvious from the symmetry of the construction and the similarity of conditions that an equal and opposite e.m.f. will be induced in the return wire, and the expression, *self-induction of the line*, may be interpreted to signify the sum of the self-inductions of the two wires forming the line, or twice the self-induction of one wire. The induced difference of potential between the two conductors may then be regarded as due to the rate of change of the flux interlinking the *circuit* or *loop* formed by the two conductors. This is plainly the sum of the two fluxes, or two times either. From this point of view, the coefficient of self-induction of three-phase three-wire lines may be readily calculated.

Consider a three-phase line with the wires arranged at the corners of an equilateral triangle, and assume, as is the common practice, that the current is a simple harmonic, *i.e.*, sine function of time.

The most general expression for a simple harmonic function is

$$I_A = I\ sin\ (\omega t + c) \qquad (20)$$

which will be used to represent the current in A. The current in B will then be

$$I_B = I\ sin\left(\omega t + c - \frac{2\pi}{3}\right) \qquad (21)$$

I is the modulus or maximum value of the complex quantity.

$(\omega t + c)$ is the amplitude or phase-angle.

$\omega = 2\ n\ \pi\ f$, where n is any integer.

The current in B lags behind the current in A by $\frac{2\pi}{3}$.

From (19) the flux linking the circuit AB is

$$\phi_{AB} = LI_A + LI_B = L(I_A + I_B)$$

and substituting the values of I_A and I_B from (20) (21) gives

$$\begin{aligned}\phi_{AB} &= LI\left(sin\left[\omega t + c\right] + sin\left[\omega t + c - \frac{2\pi}{3}\right]\right)\\ &= LI\ \left(2\ sin\left[\omega\, t + c - \frac{\pi}{3}\right]cos\left[\frac{-\pi}{3}\right]\right)\\ &= \sqrt{3}\,LI\ sin\ \left[\omega\, t + c - \frac{\pi}{3}\right] \qquad (22)\end{aligned}$$

This is obviously a sine function having the same period as I_A but lagging behind it by the angle $\frac{\pi}{3}$, and having a modulus $\sqrt{3}$ times that of I_A. From this relation the value

$$L_{AB} = \sqrt{3}\ L_A \qquad (23)$$

is directly derived. It is obvious that the flux due to the current in C produces precisely the same effect in both A and B and therefore does not affect that *circuit* at all.

The values of the self-induction for single-phase *circuits* multiplied by $\sqrt{3}$ give the values per phase (loop of two conductors) of the three-phase self-induction.

If the three-phase wires are arranged parallel in a plane and transposed, each wire occupying the central position for one-third of the way, the wires AB will be spaced the distance d for two-thirds of the way and $2d$ for one-third of the way. The self-induction of phase AB will then be,

$$2\sqrt{3}\left(\frac{2}{3}\left[ln\frac{d}{r} + \frac{1}{4}\right] + \frac{1}{3}\left[ln\frac{d}{r} + \frac{1}{4}\right]\right) \qquad (24)$$

so that the self-induction will be higher than where the wires are arranged at the corners of an equilateral triangle. The self-induction of any line may be found by calculating separately the self-inductions of the several parts into which it may be divided and adding these together.

(To be Continued)

NEW METHOD OF VOLTAGE CONTROL FOR REGULATING LARGE, SINGLE-PHASE, LOW VOLTAGE TRANSFORMERS

By E. F. Gehrkens

The General Electric Company has recently built and installed for the International Achison Graphite Company at Niagara Falls, a 1600 kw., single-phase, 25 cycle, oil and water cooled transformer for operating an electric furnace. This apparatus possesses a number of special features and a detailed description of the installation should prove of interest.

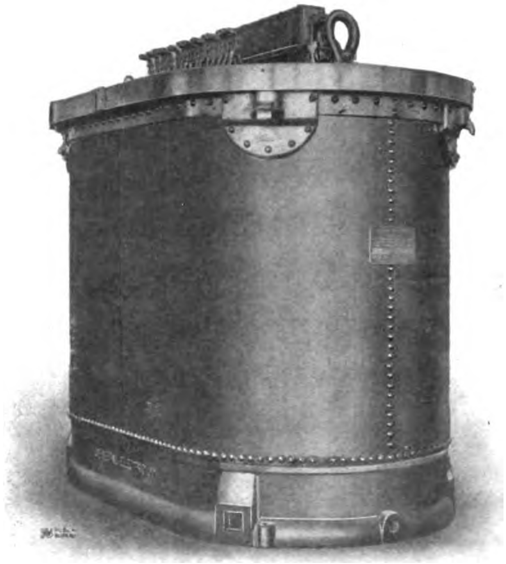

Fig. 1. 1600 Kw. Transformer, Designed for a Voltage Range of from 40 to 200 Volts on the Secondary

The transformer is wound for 2200 volts primary and 40 to 200 volts secondary, the range being obtained by means of taps in the primary and a series or parallel connection of the secondary. It is designed to deliver 1600 kw. at any voltage within the range given; that is, it has a range in the current capacity of from 8000 amperes at 200 volts to 40000 amperes at 40 volts.

This transformer is one of a number of similar (though in some cases smaller) units that have formerly been installed; these latter, however, are differently controlled. With the present transformer, the change in voltage throughout the entire range must be made gradually and not in steps; whereas those heretofore installed were controlled, either by an induction regulator connected in series with one of the windings (the regulator having sufficient capacity to produce the entire range in voltage desired), or by providing the primary of the transformer with taps connected to a dial switch, and using an induction regulator to vary the voltage gradually between the steps of the switch.

The present transformer is provided with taps in the primary and controlled by a combination of switches so arranged that, by the use of a compensator and a number of small resistances, an exceedingly simple method of control is obtained, and one giving, as nearly as can be determined by a voltmeter, a perfectly smooth regulation.

The installation consists essentially of the following apparatus:

The 1600 kw. transformers with taps in the primary and a series-parallel arrangement of the secondary as shown in Fig. 1.

A motor operated 40,000 ampere switch for connecting the secondaries of the transformer in series or in parallel (See Fig. 2.)

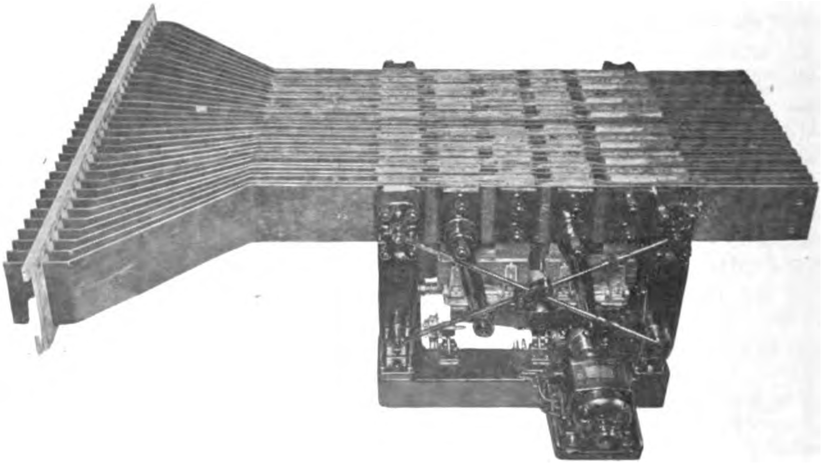

Fig. 2. 40,000 Ampere Motor Operated Switch for Secondary of Transformer

A switching device for changing the tap connections of the primary of the transformer, shown in Fig. 4.

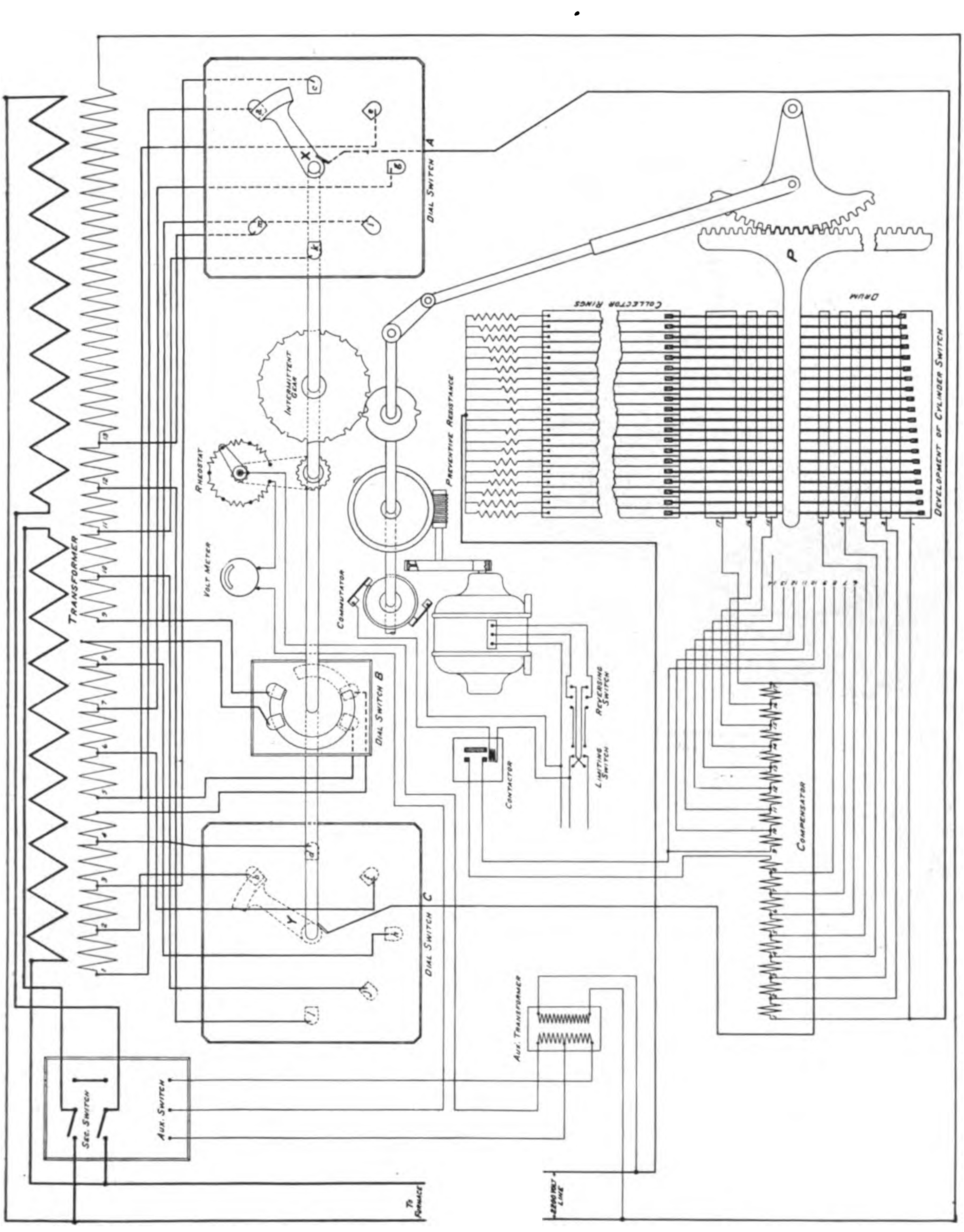
Dial Switch A
X
P
Collector Rings
Drum
Intermittent Gear
Rheostat
Preventive Resistance
Development of Cylinder Switch
Transformer
Volt Meter
Commutator
Dial Switch B
Reversing Switch
Limiting Switch
Contactor
Compensator
Dial Switch C
Y
Aux. Transformer
Sec. Switch
Aux. Switch
To Furnace
2200 Volt Line

Fig. 3. Diagram of Connections for Regulating Device

The switching device is shown diagrammatically in Fig. 5, and consists of the following detailed parts:

1. Two dial switches *A* and *C* for changing the tap connections of the primary of the transformer.

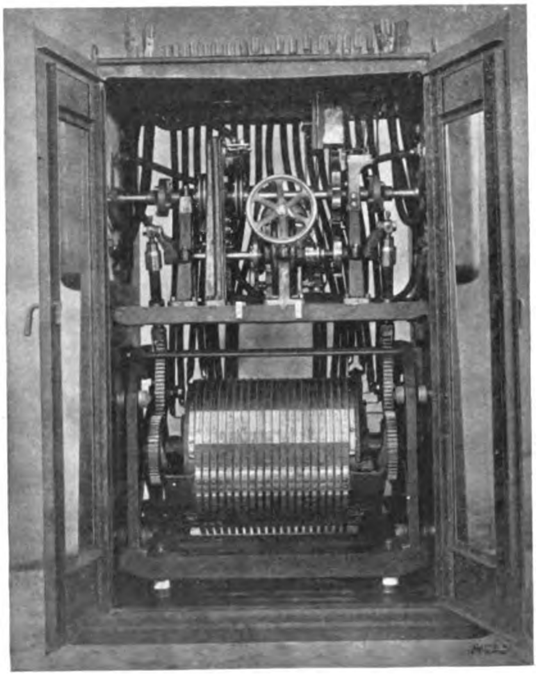

Fig. 4. View of Interior Mechanism of Switching Device for Changing Primary Tap Connections

2. A dial switch *B* for disconnecting the successive sections of the primary winding that have been cut out of circuit by dial switches *A* and *C*, so as to prevent excessive voltage across the transformer terminals as the number of active turns of the primary winding are decreased.

3. A compensator, the winding of which is subdivided into a number of equal sections and arranged so that its terminals are consecutively connected across two adjacent taps of the transformer by means of the dial switches *A* and *C*; the terminals of this compensator being permanently connected to the moving arms of the two dial switches respectively.

4. A cylinder switch with two sets of stationary collectors consisting of heavy bars, the two sets being arranged at right angles to each other and having the taps and the terminals of the compensators connected to one set, and individual resistances to the other set.

The moving member of the cylinder switch consists of a multiplication of fingers, individually insulated, by means of which the tap connection of the compensator is changed.

9. A two-part commutator controlling a contactor switch, by means of which the compensator circuit is opened as soon as the line is connected to a transformer tap direct and while the transformer tap connections are being changed by either dial switch *A* or *C*.

6. A voltmeter which is controlled by a rheostat and a potential transformer, and which indicates the voltage which will be obtained at the terminals of the furnace before the transformer is connected to the line.

7. An operating motor, shafts, and gearing, by means of which the switches are operated; the motor being furnished with a reversing switch—so as to obtain a boosting or lowering of the transformer voltage—and a limit switch to prevent it operating the mechanism beyond the range of control.

The operating motor is geared to the shaft which, by intermittent gearing, actuates the dial switches *A* and *C* and the disconnecting switch *B*, and is connected to the cylinder switch by a crank. The odd numbered taps of the transformer are connected to the dial switch *A*, and the even numbered ones to dial switch *C*; the ratio of the intermittent gearing is such that the moving member of the cylinder switch (designated as *P*) passes over the entire set of compensator collectors from top to bottom or *vice versa*, for every change of connection of either dial switch *A* or *C*. The blades of these dial switches—which are shown as *X* and *Y* respectively— are of sufficient width, and the spacing of the stationary clips (*a*) (*c*) (*e*) etc., on switch *A*, and (*b*) (*d*) (*f*) etc., on switch *C*, is such that each blade remains in contact with each clip for an entire revolution of the crank shaft; that is, during the time necessary for the moving element *P* of the cylinder switch to travel over all of the contacts in both directions.

The crank operating the cylinder switch has an angular adjustment with reference to the blades *X* and *Y* of the dial switches, such that the change in the transformer tap connections of the dial switches takes place only when the crank shaft is on its centers, in which position the movement of *P* is exceedingly small. To compensate for this small movement, both end collectors of the cylinder switch are made sufficiently wide to insure that all of the fingers of the moving element will remain on either end collector during the time required for changing the adjustment of either *X* or *Y* on switch *A* or *B*.

When the 2200 volt circuit is connected across the entire winding of the transformer, the minimum voltage will be secured across the secondary. This is obtained with *X* on (*a*) and *P* connected to tap No. 1 of the compensator. With *X* on (*a*), *Y* is also connected to (*b*), but practically no current flows through switch *C* with *P* on tap No. 1 of the compensator. The intermittent gear driving the dial switch blades is inoperative with the blades in the position shown, with reference to the stationary clips (*a*) and (*c*) on switch *A*, (*b*) and (*d*) on switch *C*. The crank is just over the center and *P* is on tap No. 1 of the compensator. As the motor rotates, the contacts *X* and *Y* remain stationary, but *P* is moved along the horizontal collectors connected to the tap and terminals of the compensator, until it reaches the further extreme, and the line is then, in effect, connected directly to tap (*b*) of the main transformer. During this operation the voltage of the secondary of the transformer has been gradually changed, because of the multiplication of fingers on *P* and the large number of taps on the compensator; the fingers of *P* being arranged so that with the center of the top finger on the center of collector No. 3 of the cylinder switch, the center of the bottom finger is on the center of collector No. 2 of the switch. As soon as *P* has reached the top collector of the cylinder switch, and the line is therefore connected direct to tap (*b*) of the transformer, the intermittent gearing engages and *X* is moved to (*c*), *Y* still remaining on (*b*). This changes the polarity of the compensator and again leaves *P* in a position such that by a continued movement of the crank the cylinder switch is again gradually changed between the next two transformer taps; that is, from (*b*) to (*c*); thus again gradually increasing the secondary voltage of the main transformer. This alternating movement of the blades *X* and *Y*, and the intermittent movement of the cylinder switch is continued until the entire range has been obtained.

With the secondary coils in multiple, the range in the secondary voltage of the transformer, for a complete range of operation of the primary switch, is from 40 to 100 volts. To obtain a higher voltage it is necessary to open the main primary switch of the transformer and entirely disconnect it from the line; then to connect the secondary of the transformer in series by means of the motor operated switch shown in Fig. 2. The operation of the primary switch must then be reversed, until the voltage across the secondary is again 100, after which the motor must be again reversed and the operation continued as before until the primary switch again reaches its limit. A voltage of 200, which is the maximum, will then be delivered by the secondary of the transformer.

In order to enable the operator to determine the adjustment of the switch with regard to the secondary voltage, before the transformer is again connected into circuit, a voltmeter connected to the secondary of a small potential transformer is provided, the primary of the latter being connected directly across the line from which the main transformer is operated. This potential transformer has a double winding, each of 100 volts, arranged as shown in the diagram, and by means of a small switch (operated by, and simultaneously with, the series-parallel switch for the secondary of the main transformer), either the full voltage or the half voltage arrangement is connected to the voltmeter, depending on whether the secondary of the main transformer is in series or in multiple.

The current from the potential transformer passes through an adjustable resistance, operated by a sprocket wheel and chain from the shaft which actuates the dial switches. This resistance is such that the voltmeter shows the approximate voltage of the secondary of the main transformer; that is, it not only shows the voltage when the transformer is in operation, but also when the main transformer is entirely disconnected from the line, it will show what the secondary voltage would be, with any primary adjustment or secondary connection, if the primary were connected to the line.

In order to avoid breaking any current whatever by means of the dial switches, a contactor switch is provided for this purpose. This contactor is excited from some suitable source of supply and controlled by a two-part commutator mounted on the main shaft. The brushes of the commutator are so adjusted that the contactor is normally energized, while the circuit is opened and thereby the commutator winding as soon as all of the fingers of *P* of the cylinder switch are on either extreme collector, and before either blade of either dial switch has opened the circuit. With this arrangement, absolutely no current is broken by either of the dial switches *A* or *C*, the breaking of the magnetizing current of the compensator having been shifted to the contactor switch, the contacts of which are readily removable.

The burning of the contacts of *P* can be reduced to a minimum by having a large number of taps on the compensator, thereby reducing the voltage between the taps to a very small amount, and also by having a large number of fingers; so that there will be practically no breaking of current, but rather a gradual shifting due to the gradually varied resistances between the compensator taps, which resistances have a sufficient capacity to allow the compensator switch to be left in any position whatever.

The arrangement described produces the same smooth and gradual regulation that is obtained with the induction regulator. The efficiency and power factor of the installation are improved, and it is, therefore, particularly adapted for use with large single-phase, low voltage transformers having large current capacity, and requiring a considerable range in voltage adjustment.

ELECTRICALLY HEATED OIL TEMPERING BATHS

By H. Fulwider

Tempering Processes

Tempering is probably the most important operation in the manufacture of steel tools. Its successful performance therefore requires that either the workman have a broad experience in this work, or a method be employed which eliminates to a considerable extent the personal factor.

The tempering process really involves two steps, hardening and drawing. The first consists in heating the steel to a temperature of from 600 deg. to 700 deg. C., depending on the amount of carbon in the steel, and then chilling it by plunging it into a cold bath of brine or running water. The temper of the tool is then "drawn" by heating it to a certain predetermined temperature, or until it shows a certain known color, after which the metal is allowed to cool gradually.

There are several ways of drawing temper, but it is usually accomplished by one of the two following methods: In one, a skilled workman judges the proper tempering temperature by degrees or shades of color; in the other, a thermometer of precision registers the temperature and the workman simply follows a chart—a physiological process against a physical one. In the former method, the steel is introduced into a furnace having a temperature between 500 deg. and 600 deg. F.; in the latter it is immersed in a liquid bath, the temperature of which is between 400 deg. and 550 deg. F. In the first case, good quality of product requires that the workman be experienced, and capable of accurately judging the degree of temper in the metal by the color shown. This means that the operator must be well paid, resulting in a consequent increase in cost of production. With the latter method, it is only necessary to have a table of temperatures corresponding to certain degrees of hardness in the steel. The operator can then place the work in the bath, bring the latter to the required temperature, indicated by a thermometer, and hold it at that temperature

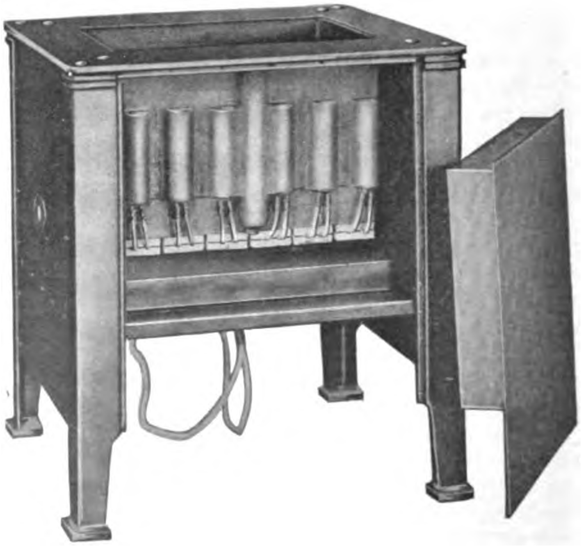

Fig. 1. Electrically Heated Oil Tempering Bath, showing Heating Units

as long as necessary. By this last method tools will be produced having a uniform degree of hardness, independent of what workman does the work. In addition to this, one man can temper a greater quantity of tools in a given time than with the air blast furnace of the first method.

Sources of Heat for Oil Tempering

Formerly the oil tempering bath was heated either by means of gas or fuel oil. These sources of heat, although satisfactory to a certain extent, are objectionable because of the fire risk resulting from an open flame, and the difficulties of obtaining close temperature regulation. Realizing these facts, the General Electric Company has developed a line of electrically heated oil tempering baths which overcome these objections. These baths can be located at any desired point in the factory with perfect safety. The temperature of the bath is easily controlled by means of regulating switches which vary the amount of energy consumed.

Construction of Electric Oil Tempering Bath

The general appearance of the electrically heated bath is shown in Figs. 1 and 2. The bath proper consists of a rectangular cast iron tank having six lugs cast vertically on each side, and evenly spaced; these lugs being drilled out so that "cartridge" type heating units can be inserted in them. It is found that by thus distributing the units, an even temperature can be maintained in all parts of the oil.

The bath is surrounded by a heat retaining jacket made up of one bottom and four side sections. These sections are built up in the form of sheet metal boxes with an internal space of 3 in., which is filled in with mineral wool. The jacketing on both sides of the tank where the units are located is easily removable. This construction allows of quick access to the internal connections of the units.

A wide flange is provided at the top of the tank, and to this are secured four cast iron legs of suitable length. A drain pipe controlled by a globe valve provides a means of drawing off the oil. At one end of the tank there is a protected recess, in which is placed the thermometer that indicates the temperature of the oil. It is through the agency of this thermometer that the proper degree of hardness can be given to the tools which are being tempered, independent of the judgment or skill of the operator.

When desired, a cast iron basket or tray can be supplied, in which are placed the tools to be tempered. The bottom of the basket is perforated with ⅞ in. holes which permit the oil to circulate and drain freely. There are feet on the bottom of the basket which keep the work at a distance of 1 in. or more above the bottom of the bath.

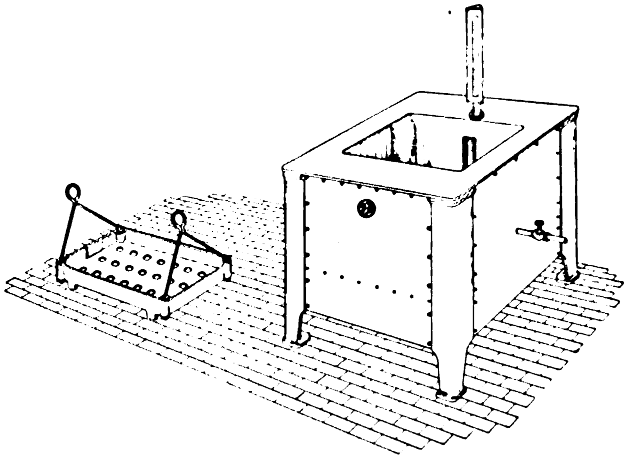

Fig. 2. Perspective, showing Electrically Heated Oil Tempering Bath and Cast Iron Basket for holding Tools when Immersed

Sizes

The following table gives inside dimensions, weight, oil capacity and energy consumption of the three standard sizes.

No.	Length	Width	Depth	Weight	Oil	Kilowatt
1	22″	12″	8″	420 lbs.	9 gal.	6
2	18″	12″	12″	475 lbs.	11 gal.	7.2
3	30″	16″	18″	900 lbs.	37 gal.	20

Note: All sizes furnished for either single or multiple heat control.

Tempering Temperatures of Tools

The maximum energy consumption of these baths is sufficient to heat the oil to a temperature of 450 deg. F.; in less than one hour, starting cold. The maximum temperature which it is possible to obtain is about 600 deg. F.; which is very close to the flashing point of the oil commonly used for tempering purposes. The following is a list of tools, with the temperatures to which they should be raised in drawing the temper.

430° F.	Scrapers for brass Steel-engraving tools Slight turning tools Hammer faces Planer tools for steel Ivory-cutting tools Planer tools for iron Paper cutters Wood-engraving tools Bone cutting tools
460° F.	Milling-cutters Wire-drawing dies Boring-cutters Leather-cutting dies Screw-cutting dies Inserted saw-teeth Taps Rock-drills Chasers Punches and dies Penknives Reamers Half-round bits Planing and moulding cutters Stone-cutting tools
500° F.	Gouges Hand-plane irons Twist-drills Flat drills for brass Wood-boring cutters Drifts Coopers' tools Edging cutters
530° F.	Augers Dental and surgical instruments Cold chisels for steel Axes
550° F.	Gimlets Cold chisels for cast iron Saws for bone and ivory Needles Firmer-chisels Hack-saws Framing-chisels Cold chisels for wrought iron Moulding and planing cutters to be filled Circular saws for metal Screw-drivers Springs Saws for wood

It will be noted that the temperatures to which the above tools should be raised in tempering are all within the range of the electrically heated oil tempering bath.

Methods of Oil Tempering

In shop practice there seems to be a difference of opinion in the matter of drawing the temper of tool steel, the point of contention being: whether the steel should be gradually raised to the tempering point, or whether it should be plunged into a bath which is already at the tempering temperature.

This difference gives rise to two methods of oil tempering. The first is to bring the bath to a temperature of about 250 deg. F. then place the work in the bath, and turn on full heat until the oil reaches the desired temperature, when the current is turned off and the work removed. If this procedure is followed, the steel, being introduced at a comparatively low temperature and then gradually heated to the proper point, is not subjected to any shock, and there is therefore no danger of injuring the quality of the tools.

The second method is to maintain the oil bath at the required temperature and plunge the steel into the oil, allowing it to remain there just long enough to acquire the same temperature evenly throughout the metal. The tools are then removed and a new lot is submerged.

By this latter method the process of tempering can be carried on without interruption, whereas in the first method it is necessary each time to cool the bath down to a temperature of about 250 deg. F. before introducing a new lot of steel, with a consequent decrease in output. Thus both methods have their advantages; but the one of gradual heating up involves no doubt as to the quality of the tool.

Control and Regulation

The heating units of the electrically heated baths are connected in groups, arranged according to the size of the bath, and the leads brought out to the terminal block. The bath can then be used as a single heat device; or, by running the leads to a switchboard designed for the purpose, it is possible to obtain a great number of temperatures. Where the tempering is done by gradually heating up the steel, the single heat bath will do the work satisfactorily; but if it is desired to maintain a constant temperature, it will be necessary to have the multiple heat bath, in which means are provided for varying the energy input by small steps, from zero to maximum. In the latter bath, each group of units is controlled at the panel board by an individual switch, and any desired temperature is obtained by throwing in the number of units necessary to give that temperature approximately. Close regulation is then secured by varying the voltage impressed on one of the units, this being effected by means of a rheostat, also mounted on the controlling board.

AERONAUTICAL

The international balloon race for the Gordon Bennett trophy, which started from Zurich on Sunday, October 3rd, was won by Edward W. Mix, of the Compagnie Francaise Thomson-Houston. Mr. Mix is a native of Columbus, Ohio, and was connected at one time with the old Thomson-Houston Company, of Lynn. The following description of his flight, which was sent to the press by him, will be read with interest by many of his former associates.

"Leaving Zurich Sunday at 3 : 57 p.m., we were able to recognize our location as far as Constance. At the finish the weather was so thick that direction could only be determined by compass. In a drenching rain during Sunday night, the balloon sometimes seemed to be at a complete standstill. We ascended and descended in search of better currents of air, without appreciable results. By 4 o'clock in the morning half of our ballast had been used.

"The passage of the Bavarian Alps through rain and clouds was thrilling. Once we swooped down the mountainside with frightful velocity, plunging into a chasm of fog which seemed bottomless; it was as if the earth had opened to swallow us. The basket several times crashed through tree tops. When clear of the mountains we moved at a lively rate. The guide rope dragged over farm houses, breaking tiles and chimneys. The peasants rushed out with cries and imprecations. A few hours later we recognized several villages and then the town of Konigstadt. We sighted a balloon to the eastward with peasants hanging onto the guide rope.

"After passing over Konigstadt we rose through the clouds to an altitude of 4,600 metres (about 15,000 feet), and saw above the clouds a balloon to the north, about 100 metres higher. We began to descend at 1 : 40 p.m., emerging from the clouds about 460 metres above the town of Waldenburg, and were obliged to jettison eleven sacks of ballast and half of our provisions to keep clear of the roofs, but as it was, the guide rope dragged over the wires of the fortress and railroad station, creating consternation among the yelling population.

"We arose again to 2,800 metres, throwing overboard the life savers, mattresses and the remainder of our provisions. Gradually we continued to descend after reaching that altitude, until 6 o'clock in the evening. With good equilibrium we managed to keep afloat until 3 o'clock Tuesday morning without expenditure of ballast, of which, as a matter of fact, there was not an ounce left.

"The balloon landed—and became wedged between pine trees in the forest of Gutova. We waited until 6 : 30 before defaulting and then searched for help. We found peasants, one of whom had been in America and spoke a little English. With their aid we loaded the balloon on carts to be taken to Ostrolenko.

"On our arrival at Ostrolenko we were stopped by the police, who took us together with the balloon to the station, where we remained until instructions were received from St. Petersburg for our release. We were treated excellently."

PUBLICATIONS

The following publications have been issued by the Publication Bureau of the General Electric Company during the last few weeks:

4698 Describes and illustrates the improved luminous arc headlights as now manufactured by the General Electric Company for both street railway and mining service. Complete wiring diagrams are furnished, showing methods of wiring headlight in series with special resistance, or in series with incandescent bulbs for lighting car.

4699 Describes new form of air compressor, which is manufactured in three capacities; *i.e.*, 15, 25 and 35 cu. ft. piston displacement. The general construction of the motor, frame, bearings, lubrication, gears, etc., are well outlined and illustrated, and a table of general dimensions, weights, speeds and capacities is also incorporated.

4700 Sets forth the general electrical and mechanical features of the General Electric Type R-2 Switchboard Instruments.

4701 The advantages of the emergency straigh air brake system for city railways, where traffic is more or less congested during certain hours of the day, are enumerated in this bulletin. The various importan features of the equipment, such as air compressors, governor, combined switch and fuse, and motorman's valve are taken up separately and fully described.

TABLE XX

CHARGING CURRENT

SINGLE-PHASE

STRANDED CONDUCTORS

Chg. Current 1571 C.
Multiply Values by 10^{-2}

In Amperes per 1000 Feet of Line (2000 Feet of Wire)

f - 25 Cycles
E - 1000 Volts

Interaxial Distance, Inches	SIZE OF WIRE													
	500,000	450,000	400,000	350,000	300,000	250,000	0000	000	00	0	1	2	3	4
1	.3650	.2842	.2382	.2005	.1712	.1463	.1303	.1126	.1003	.0910	.0820	.0754	.0702	.0655
2	.0980	.0927	.0886	.0839	.0794	.0745	.0707	.0660	.0621	.0588	.0553	.0524	.0502	.0478
3	.0721	.0698	.0672	.0648	.0620	.0592	.0570	.0539	.0514	.0492	.0468	.0448	.0431	.0413
4	.0613	.0594	.0578	.0560	.0540	.0520	.0503	.0479	.0460	.0442	.0423	.0405	.0393	.0379
5	.0550	.0536	.0524	.0508	.0192	.0476	.0462	.0442	.0426	.0410	.0394	.0380	.0368	.0355
6	.0509	.0497	.0486	.0473	.0460	.0450	.0432	.0415	.0401	.0387	.0372	.0360	.0350	.0339
9	.0437	.0427	.0419	.0410	.0401	.0390	.0380	.0368	.0356	.0346	.0334	.0324	.0316	.0306
12	.0398	.0390	.0383	.0376	.0368	.0358	.0350	.0339	.0330	.0321	.0311	.0302	.0295	.0287
18	.0354	.0347	.0343	.0336	.0330	.0323	.0316	.0307	.0300	.0292	.0284	.0276	.0270	.0264
24	.0328	.0323	.0319	.0314	.0308	.0302	.0296	.0288	.0281	.0275	.0267	.0261	.0255	.0249
30	0311	.0306	.0302	.0297	.0292	.0287	.0282	.0275	.0268	.0262	.0256	.0250	.0245	.0240
36	.0298	.0294	.0290	.0286	.0281	.0276	.0271	.0265	.0259	.0253	.0247	.0242	.0237	.0232
42	.0288	.0284	.0281	.0276	.0272	.0267	.0263	.0257	.0251	.0246	.0240	.0235	.0230	.0226
48	0280	.0276	.0273	.0269	.0265	.0260	.0256	.0250	.0245	.0240	.0235	.0230	.0225	.0221
54	.0273	.0269	.0266	.0263	.0259	.0254	.0250	.0245	.0240	.0235	.0230	.0225	.0221	.0217
60	.0267	.0264	0261	.0257	.0253	.0249	.0245	.0240	.0235	.0231	.0225	.0221	.0217	.0213
72	.0258	.0255	.0251	.0218	.0245	.0241	.0237	.0233	.0228	.0224	.0219	.0215	.0211	.0207
84	.0250	.0247	.0244	.0241	.0238	.0234	.0231	.0226	.0222	.0218	.0213	.0209	.0206	.0202
96	.0243	.0241	.0239	.0235	.0232	.0229	.0226	.0221	.0217	.0213	.0209	.0205	.0202	.0198
108	.0239	.0236	.0234	.0231	.0228	.0224	.0221	.0217	.0213	.0209	.0205	.0201	.0198	.0195
120	.0234	.0232	.0229	.0227	.0224	.0220	.0217	.0213	.0209	.0206	.0202	.0198	.0195	.0192
132	.0230	.0228	.0226	.0223	.0220	.0217	.0214	.0210	.0206	.0203	.0199	.0196	.0192	.0189
144	.0227	.0225	.0222	.0220	.0217	.0214	.0211	.0207	.0203	.0200	.0196	.0193	.0190	.0187
156	.0224	.0222	.0219	.0217	.0214	.0211	.0208	.0205	.0201	.0198	.0194	.0191	.0188	.0185
168	.0221	.0219	.0217	.0214	.0212	.0209	.0206	.0203	.0199	.0196	.0192	.0189	.0186	.0183
180	.0218	.0216	.0214	.0212	.0209	.0207	.0204	.0200	.0197	.0194	.0190	.0187	.0184	.0181

Single Phase.

TABLE XXI

CHARGING CURRENT

SINGLE-PHASE

STRANDED CONDUCTORS

Chg. Current = .377 C.
Multiply Values by 10^{-2}

In **Amperes** per 1000 Feet of Line (2000 Feet of Wire)

f = 60 Cycles
E = 1000 Volts

Interaxial Distance, Inches	SIZE OF WIRE													
	500,000	450,000	400,000	350,000	300,000	250,000	0000	000	00	0	1	2	3	4
1	.8770	.6820	.5720	.4812	.4110	.3515	.3130	.2701	.2410	.2181	.1967	.1810	.1685	.1572
2	.2350	.2223	.2125	.2013	.1903	.1786	.1696	.1583	.1490	.1410	.1327	.1255	.1202	.1145
3	.1730	.1674	.1613	.1552	.1490	.1420	.1368	.1293	.1232	.1180	.1123	.1075	.1033	.0991
4	.1470	.1425	.1387	.1342	.1297	.1248	.1206	.1150	.1103	.1060	.1015	.0973	.0942	.0908
5	.1320	.1285	.1255	.1217	.1180	.1142	.1108	.1060	.1022	.0984	.0944	.0910	.0882	.0852
6	.1221	.1190	.1165	.1135	.1108	.1078	.1036	.0995	.0961	.0930	.0894	.0863	.0841	.0813
9	.1048	.1025	.1006	.0984	.0961	.0935	.0912	.0882	.0854	.0829	.0802	.0777	.0758	.0735
12	.0953	.0935	.0920	.0901	.0882	.0860	.0840	.0814	.0792	.0770	.0747	.0726	.0709	.0689
18	.0848	.0833	.0822	.0807	.0792	.0776	.0758	.0737	.0719	.0701	.0681	.0664	.0649	.0634
24	.0788	.0775	.0765	.0752	.0739	.0724	.0710	.0691	.0674	.0659	.0641	.0626	.0613	.0599
30	.0746	.0735	.0724	.0714	.0701	.0688	.0676	.0659	.0644	.0630	.0614	.0600	.0588	.0575
36	.0716	.0705	.0696	.0686	.0675	.0662	.0650	.0635	.0620	.0608	.0592	.0580	.0569	.0556
42	.0690	.0681	.0673	.0663	.0653	.0641	.0631	.0616	.0602	.0590	.0577	.0564	.0553	.0542
48	.0671	.0662	.0654	.0645	.0636	.0624	.0614	.0600	.0588	.0576	.0563	.0550	.0541	.0532
54	.0656	.0646	.0640	.0630	.0621	.0611	.0601	.0588	.0575	.0564	.0551	.0540	.0530	.0520
60	.0641	.0633	.0626	.0617	.0608	.0598	.0589	.0576	.0364	.0553	.0541	.0530	.0521	.0311
72	.0618	.0611	.0603	.0596	.0588	.0578	.0569	.0558	.0546	.0537	.0526	.0515	.0506	.0496
84	.0599	.0593	.0586	.0579	.0571	.0563	.0554	.0543	.0533	.0523	.0512	.0502	.0494	.0484
96	.0584	.0379	.0573	.0566	.0558	.0549	.0542	.0531	.0521	.0512	.0502	.0492	.0484	.0475
108	.0573	.0566	.0560	.0554	.0546	.0538	.0532	.0521	.0311	.0502	.0492	.0483	.0475	.0467
120	.0562	.0556	.0350	.0544	.0537	.0529	.0522	.0512	.0302	.0494	.0484	.0475	.0467	.0459
132	.0552	.0546	.0542	.0535	.0528	.0521	.0514	.0504	.0496	.0487	.0477	.0469	.0459	.0453
144	.0545	.0539	.0534	.0528	.0521	.0514	.0507	.0497	.0488	.0481	.0471	.0463	.0455	.0448
156	.0537	.0531	.0526	.0520	.0514	.0307	.0500	.0492	.0482	.0475	.0466	.0457	.0451	.0443
168	.0530	.0525	.0520	.0514	.0508	.0502	.0495	.0486	.0477	.0469	.0461	.0452	.0446	.0439
180	.0524	.0518	.0514	.0509	.0503	.0496	.0489	.0481	.0473	.0465	.0456	.0449	.0441	.0434

Single Phase.

TABLE XXII

CHARGING CURRENT

SINGLE-PHASE

STANDARD CONDUCTORS

Chg. Current = .6283 C.
Multiply Values by 10^{-2}

In Amperes per 1000 Feet of Line (2000 Feet of Wire)

$f = 100$ Cycles
$E = 1000$ Volts

Interaxial Distance, Inches	SIZE OF WIRE													
	500,000	450,000	400,000	350,000	300,000	250,000	0000	000	00	0	1	2	3	4
1	1.461	1.138	.954	.803	.685	.586	.522	.451	.402	.364	.328	.302	.281	.262
2	.392	.371	.355	.336	.317	.298	.283	.264	.248	.233	.221	.209	.201	.191
3	.288	.279	.269	.259	.248	.237	.228	.216	.206	.197	.187	.179	.172	.165
4	.245	.238	.231	.224	.216	.208	.201	.192	.184	.177	.169	.162	.157	.152
5	.220	.214	.209	.203	.197	.190	.185	.177	.170	.164	.157	.152	.147	.142
6	.204	.199	.194	.189	.184	.180	.173	.166	.160	.155	.149	.144	.140	.135
9	.175	.171	.168	.164	.160	.156	.152	.147	.142	.138	.134	.129	.126	.123
12	.159	.156	.153	.150	.147	.143	.140	.136	.132	.128	.124	.121	.118	.115
18	.142	.139	.137	.135	.132	.129	.126	.123	.120	.117	.114	.111	.108	.106
24	.131	.129	.128	.126	.123	.121	.119	.115	.113	.110	.107	.104	.102	.0998
30	.124	.122	.121	.119	.117	.115	.113	.110	.107	.105	.102	.100	.0981	.0959
36	.119	.118	.116	.114	.113	.110	.108	.106	.104	.101	.0988	.0967	.0948	.0927
42	.115	.1136	.1122	.1106	.1088	.1075	.1053	.1027	.1004	.0984	.0962	.0940	.0922	.0903
48	.112	.1105	.1091	.1076	.1060	.1041	.1024	.1002	.0981	.0961	.0939	.0918	.0902	.0887
54	.1094	.1078	.1066	.1051	.1035	.1018	.1002	.0980	.0959	.0940	.0919	.0900	.0884	.0866
60	.1068	.1056	.1043	.1030	.1014	.0997	.0982	.0961	.0941	.0923	.0902	.0884	.0869	.0852
72	.1031	.1018	.1006	.0993	.0981	.0965	.0949	.0930	.0912	.0895	.0876	.0858	.0844	.0827
84	.1000	.0990	.0978	.0966	.0953	.0939	.0924	.0905	.0889	.0873	.0854	.0838	.0824	.0808
96	.0974	.0965	.0955	.0943	.0931	.0916	.0903	.0885	.0869	.0854	.0836	.0820	.0808	.0792
108	.0955	.0944	.0935	.0924	.0912	.0898	.0886	.0869	.0853	.0838	.0821	.0806	.0792	.0778
120	.0936	.0927	.0918	.0907	.0896	.0882	.0871	.0854	.0838	.0824	.0808	.0792	.0780	.0766
132	.0922	.0911	.0903	.0892	.0882	.0869	.0857	.0841	.0826	.0811	.0795	.0782	.0766	.0756
144	.0908	.0899	.0890	.0880	.0869	.0856	.0846	.0829	.0814	.0802	.0786	.0772	.0760	.0748
156	.0896	.0886	.0878	.0868	.0858	.0846	.0834	.0820	.0804	.0792	.0776	.0763	.0751	.0739
168	.0885	.0876	.0867	.0858	.0848	.0836	.0825	.0810	.0796	.0783	.0768	.0755	.0744	.0732
180	.0874	.0865	.0858	.0849	.0838	.0827	.0815	.0802	.0788	.0776	.0761	.0748	.0736	.0724

Single-Phase.

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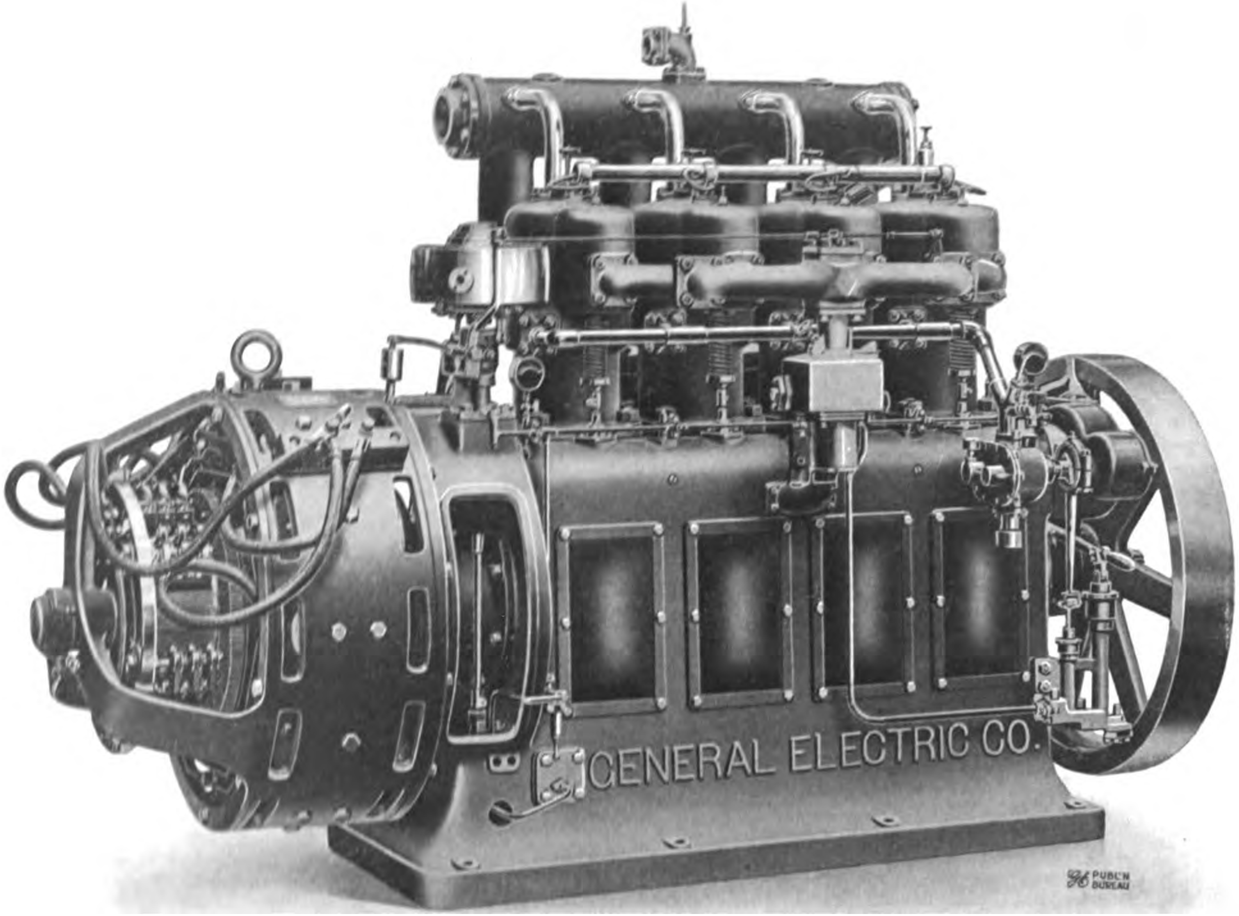
GENERAL ELECTRIC CO.
PUBL'N BUREAU

25 Kw. Gasolene-Electric Generating Set
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GENERAL ELECTRIC REVIEW

DEVELOPMENT OF WATER POWER IN THE SOUTHERN STATES

When some years ago a group of capitalists built and operated the new modern motor-driven cotton mills at Columbia, S. C., and elsewhere (thereby bringing an up-to-date manufacturing industry to the locality producing the raw material), the enterprise was watched with the interest that attends all industrial departures; it being considered in the nature of an innovation.

Of course, the old fashioned cotton mill had existed for many years, but the advent of the modern, motor-driven mill constituted a distinct industrial epoch. Thereafter modern mills began to spring up all over the lower southern States, local water power being developed to meet their needs.

As has been said by Mr. H. von Schon:* "It needs no argument to convince that the hydro-power source is the most economical of all when the power element, water, is assured with reasonable constancy, nor can the economical character of the hydro-electric power plant and its equipment, as compared with any other type, be doubted, while economy of operation is of itself evident, as there is no fuel charge, and the costs, maintenance and depreciation are trivial when compared with these items in any other type of power plant. That the individual electric motor, as compared with the mechanical drive of shafts, pulleys and belts, is safe, clean, noiseless and economical, is also self-evident; in fact, * * * the economy of the electric power current, registering through a meter only so much energy as actually performs work, appears so great that even at high current rates it may not exceed 50 per cent. of that of the most economical steam power service; in fact, the power consumer enjoys the privilege of paying for so much power only as he actually uses in the work."

The article on the Southern Power Company, in the present issue of the Review, describes the latest and by far the largest hydro-electric development in the south. As stated by Mr. Liston, the water power resources of the Company aggregate 320,000 horse-power. For the development of 270,000 horse-power of this, plans have already been prepared; this latter figure includes those stations that are complete or in course of construction.

The industrial activity that has followed in the wake of this development is shown by the following facts: When the Company was first organized, the total power supplied was 1460 horse-power, furnished to three mills in one town. At present 70,000 horse-power is delivered to 110 cotton mills in 42 cities; 41 of these are new mills designed for electric drive. In the city of Charlotte alone the horse-power employed has increased from 250 to 2450. Thirty towns, with an aggregate population of 306,000, are lighted from the Company's lines.

In connection with this development, it may be of interest to note that, as shown by Mr. von Schon, the southern States have a greater field for hydro-electric development than any other portion of the United States, the undeveloped water power in the various sections being as follows:

New England, 600,000 h.p.; New York, Pennsylvania and Middle States, 1,650,000 h.p.; Northern and North Western States, 1,050,000 h.p.; Pacific Coast watershed, 800,000 h.p.; Southern States, 4,000,000 h.p.

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* "The Conservation and Use of Water-Power Resources" by H. von Schon, *Engineering Magazine*, October, 1908.

PREDETERMINING VOLTAGE VARIATION IN D.C. MACHINES

The article in this issue entitled, "A Graphical Method of Predetermining Voltage Variation in D.C. Machines," by Mr. Edwin Place, gives a general method for analyzing the action of direct current machines subjected to a change in either the speed, load, or field control. The author assumes for the purpose of analysis that the saturation curve and certain other constants of the machine are known from previous calculation, or from data obtained experimentally.

After a machine is constructed, it may be said to be fixed so far as its electrical constants are concerned. The voltage at its terminals will then be dependent upon the relation existing between the three elements, speed, load, and field excitation. In some cases, perhaps, this relation may be so simple that it becomes possible to calculate approximately what voltage will result from a particular change in either of these elements. However, an accurate predetermination can be made by a graphical process which is logically exact, and which is applicable to the shunt or compound wound, self or separately excited machine. The graphical method given is based on elementary principles and affords a simple and direct means for obtaining the characteristic and compounding curves of a generator, or for working out special cases regarding the action of a machine. It also indicates how the data can be deduced for the proper field winding to give a desired compounding under load.

A special case considered is that of a compound wound generator driven with a constant torque applied to the shaft, and is worked out in a general way to determine what resistance must be inserted in the armature circuit in order that the resulting current shall give the proper load to maintain a given speed. In this instance, the conditions are such as to make the solution appear indeterminate at first; but the graphical method, when applied to the analysis of the problem, gives complete and definite results.

Since the action of both generators and motors is based on the same fundamental principles, it is obvious that the graphical method outlined in the article can also be used for dealing with the action of direct current motors. When so employed, this method will show what speed variations will result from changes in load or impressed voltage, and will serve to determine the proper field winding to give a desired change in speed from no load to full load.

CONSTANT CURRENT REGULATORS

In the June issue of the REVIEW we published a description of three types of voltage regulators for alternating current machines. In the present issue Mr. Laycock describes two forms of constant current regulators. The first of these is used in conjunction with a motor which is connected across the line of a railway generator, and which, being equipped with a heavy flywheel, acts sometimes as a motor and again as a generator. The second regulator described is that used with a storage battery and booster. The article closes with a description of certain applications of these devices to alternating current systems.

As we have had occasion to say in commenting upon the previous article, these regulators, both constant voltage and constant current, depend upon a principle which is entirely foreign to other types of regulators. As a rule, these latter operate by altering the resistance in the generator field circuit, and on account of the inertia of the moving parts and their distances of travel, they cannot respond quickly enough to prevent fluctuation; for the same reasons they are susceptible to hunting.

The type of regulator described by Mr. Laycock operates by rapidly opening and closing a shunt circuit around the direct current field rheostat. This it does with the utmost rapidity, three hundred to four hundred times a minute; an operation made possible only by the extreme lightness of the contact arm and its short distance of play—about one-sixteenth of an inch. The generator may thus be considered as rapidly receiving successively contradictory orders; it is bidden to build up an increased voltage (or current), but before it has more than begun to obey the order, it is directed to weaken field and drop voltage, which order is in turn instantly contradicted. Under the circumstances, the machine does not obey either order fully but takes a middle course and thus preserves a perfect balance.

In the June REVIEW the various forms of regulators were classified according to their uses. The article appearing in that issue described Class IV of the list, while the present article is devoted to Classes II, III and V. The remaining forms will be described in an early issue.

COMMERCIAL ELECTRICAL TESTING

PART II

BY E. F. COLLINS

SUPERINTENDENT OF TESTING DEPARTMENT

Core Loss

Three methods are used by the Testing Department to measure the core losses on rotating direct current apparatus and alternating synchronous apparatus. They are known as follows: "running light core loss," "belted core loss," and "deceleration core loss." The "running light" test is made on all direct current generators and motors which are given a running test. It is occasionally, though not frequently, employed with alternating current synchronous apparatus.

The following conditions must obtain with direct current apparatus in order to give satisfactory results: Brushes must be shifted on the commutator to the no-load neutral point; the spring tension must be normal, and the commutator clean, so that the normal operating commutator and brush friction values are obtained. This test, wherever possible, should be made after all the others have been finished, in order to have a glossy commutator, with its surface in good operating condition. The driving power should be supplied from a variable voltage circuit that is not subject to sudden fluctuation. Since the power input required to drive the machine running free as a motor must be obtained, its value must not be read when the rotating parts are either accelerating or decelerating. A steady voltage must be kept on the armature and the field current must have a constant value.

When "running light" tests are made on direct current generators, the observations must be made with full load field flux. The potential applied to the armature must be equal to the normal rated voltage of the generator, increased by the CR drop in the armature at full load. With this voltage impressed, the field current is varied until normal speed is obtained, when careful readings must be made of armature current, armature voltage, field current, field voltage and speed.

If the machine in test is a direct current motor, the voltage applied to the armature should be equal to the normal rated voltage of the motor, less the CR drop in the armature under full load. The field current is then adjusted to give normal speed, and electrical and speed readings taken as outlined above for direct current generators.

The power supplied to machines running free will equal that absorbed in bearing friction, brush friction, windage, and core loss, when the armature C^2R losses have been subtracted.

In making records of these tests, the testing record should clearly show whether the running light current consists of the armature current plus the shunt field current, or whether it is the armature current alone. To check this point, open the armature circuit with the shunt field circuit closed, and note whether any current is indicated on the ammeter, reading the power supplied. If no current is indicated, the reading indicates the armature current alone; otherwise, the running light current is equal to the sum of the armature and field currents. To obtain "running light" core loss tests, only a single field winding must be used for excitation; this must be a shunt field winding.

In order to obtain running light core loss upon alternating synchronous machines (in which class rotary converters are not included, as the core loss test on these machines is similar to that on direct current machines), they should be operated as synchronous motors at the proper frequency and rated voltage. For the best results, both frequency and voltage must have a steady value.

With normal voltage on the armature, the direct current field should be varied until minimum armature current is obtained. Readings should then be taken of amperes and voltage on all the phases. At minimum input current unity power factor obtains, and therefore the power to drive such machines will be the volt-ampere input. Wattmeters may be used in addition to check the volt-ampere readings. This measurement includes friction and windage losses, together with open circuit core loss plus the C^2R loss in the armature. If the value of the core loss need not be separated from the other losses, the test is useful for checking up full load efficiencies. For direct current apparatus this test is obtained quickly and at less expense than by other more elaborate methods, and the results are just as accurate and satisfactory.

The "belted core loss" method separates the core loss from the bearing friction, brush friction, and windage. A small direct current motor is used to drive the machine under test as a generator at its rated speed. A belt drive between these machines is most commonly used. However, wherever great accuracy or a high speed is necessary, direct driving by a coupling is often used.

The driving motor for this test must be carefully chosen. It must be operated with good commutation and with a fixed setting

TABLE II

Open Circuit Core Loss on a 500 Kw., 600 Volt, 360 R.P.M., 60 Cycle, 3-Phase Generator

	DRIVING MOTOR						GENERATOR					
	Volts Arm.	Amps. Arm.	Amps. Field	Speed R.P.M.	C.E. Input	C^2R	C.E. —C^2R	Core Loss	Volts Arm.	Volts Field	Amps. Field	Speed R.P.M.
	116.0	178.0	2.5	500	20650	245	20405	11820	604	80.2	62.0	360
Friction	113.5	76.0	2.5	500	8630	45	8585	0	0	0	0	360
	114.0	85.0	2.5	500	9700	55	9645	1060	152	20.0	3.9	360
	114.2	90.0	2.5	500	10280	62	10218	1633	204	25.8	18.7	360
	114.3	95.5	2.5	500	10900	70	10830	2245	262	32.2	24.0	360
	114.5	103.0	2.5	500	11800	82	11718	3133	322	38.8	29.6	360
Friction	113.5	76.0	2.5	500	8630	45	8585	0	0	0	0	360
	114.5	112.0	2.5	500	12820	96	12724	4139	386	46.9	36.4	360
	114.6	126.0	2.5	500	14420	122	14298	5713	453	54.6	42.6	360
	115.0	145.0	2.5	500	16700	162	16538	7953	515	63.7	50.2	360
	115.4	160.0	2.5	500	18450	200	18250	9665	562	71.2	56.2	360
Friction	113.5	76.0	2.5	500	8630	45	8585	0	0	0	0	360
	115.5	166.0	2.5	500	19200	212	18988	10403	570	74.0	58.0	360
	115.8	173.0	2.5	500	20000	230	19770	11185	594	78.0	61.0	360
	116.0	178.0	2.5	500	20650	245	20405	11820	604	80.5	62.0	360
	116.5	185.0	2.5	500	21580	263	21317	12732	624	84.6	65.7	360
	116.8	212.0	2.5	500	24800	345	24455	15870	684	100.5	78.4	360
	117.0	238.0	2.5	500	27850	435	27415	18830	721	117.5	90.9	360
	Motor	Running Light										
	113.0	15.4	2.5	500	1780		1780	6905	Friction and		Windage	

Driving Motor MP-4-60-550-125 V. Res. Hot. =.0077 Ohms.

TABLE III

Short Circuit Core Loss on a 500 Kw., 600 Volt, 360 R.P.M., 60 Cycle, 3-Phase A.C. Generator

	DRIVING MOTOR						GENERATOR					
	Volts Arm.	Amps. Arm.	Amps. Field	CE. Input	C^2R	C.E. —C^2R	Core Loss + Gen. C^2R	C^2R	Core Loss	Amps. Arm.	Amps. Field	Speed R.P.M.
	115.0	140.0	2.5	16100	150	15950	7365	5450	1915	480	24.8	360
Friction	113.5	76.0	2.5	8630	45	8585	0	0	0	0	0	360
	114.0	93.0	2.5	10600	66	10535	1950	1320	630	236	12.4	360
	113.8	94.0	2.5	10710	68	10640	2055	1680	375	266	14.0	360
	113.5	106.0	2.5	12050	86	11965	3380	2540	840	328	18.0	360
	114.2	115.0	2.5	13130	102	13030	4445	3440	1005	382	19.8	360
	115.0	125.0	2.5	14380	120	14260	5675	4130	1545	418	21.6	360
Friction	113.5	76.0	2.5	8630	45	8585	0	0	0	0	0	360
	114.2	130.0	2.5	14850	130	14720	6135	4540	1595	438	22.6	360
	115.0	140.0	2.5	16100	150	15950	7365	5450	1915	480	24.8	360
	115.2	158.0	2.5	18200	192	18010	9425	6780	2645	536	27.6	360
	114.2	176.0	2.5	20100	238	19860	11275	8350	2925	594	30.6	360
	115	204.0	2.5	23450	320	23130	14545	10400	4145	662	34.0	360
	116	232.5	2.5	27000	415	26585	18000	12700	5300	732	37.5	360

Driving Motor MP-4-60-550-125 V. Res. Hot=.0077. Generator Res. between Lines=.0158 Av.

of the brushes, through the range of load required for the core loss test. Ordinarily, a safe rule to follow is that the motor should be of approximately 10 per cent. of the capacity of the machine under test. The maximum load which this motor should carry with the heaviest field on the machine under test, should not exceed 50 per cent. of its normal rated capacity. The driving motor should be operated as nearly as possible at its rated speed and field strength; the brushes should be carefully set at the best position for good commutation at all the loads required by the test; and the commutator surface should be in first class condition.

The weight and width of the belt must be selected to give minimum loss. When testing motor-generator sets, rotary converters, and other apparatus that does not use belts, the tension of the belt must be kept as low as practicable, so that the bearing friction is not increased due to the belt pull. Endless belts should be used in preference to laced belts.

The driving motor must be wired so that readings may be taken of amperes armature, volts armature, amperes field, and speed. A reading should be taken on the motor corresponding to normal speed of the machine under test. The machine under test should be wired with its field separately excited and provision made for reading amperes field, volts field, and volts armature. Careful resistance measurements of the armature of the driving motor must be made previous to starting the test.

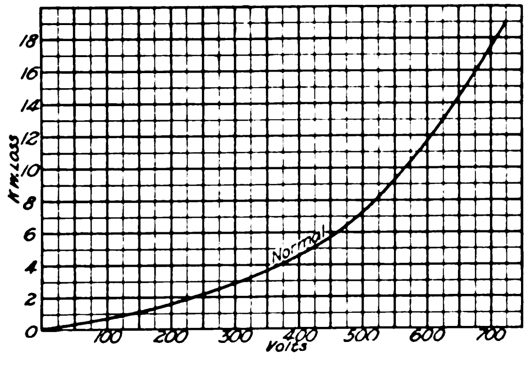


Fig. 6. Open Circuit Core Loss on a 500 Kw., 600 Volt, 20 Pole 360 R.P.M., 3-Phase, 60 Cycle, A.C. Generator

The test is then carried out as follows: The field of the driving motor is adjusted to about normal value and excited from a source of constant voltage, so that its value may be held constant throughout the test. The speed of the driving motor is regulated by varying the voltage applied to its armature terminals. First run the driving motor and the machine under test a sufficient length of time to allow the friction to reach a constant value. This will obtain when the input on the driving motor becomes constant while driving the machine under test without any field excitation. Careful readings should then be taken, first of the input to the driving motor with the machine under test unexcited and all brushes down on the commutator; and second, with all brushes raised from the commutator of the machine under test. The difference between these two sets of readings will give the brush friction on the machine being tested. Starting with zero field on the machine under test, observations of the input to the driving motor should be made at various values of the field current, up to that which will give 125 per cent. normal load voltage. Correcting the motor input at these various field strengths by subtracting the C^2R loss of the armature of the driving motor and the power input to the driving motor for zero field, the core loss corresponding to the various field strengths is found.

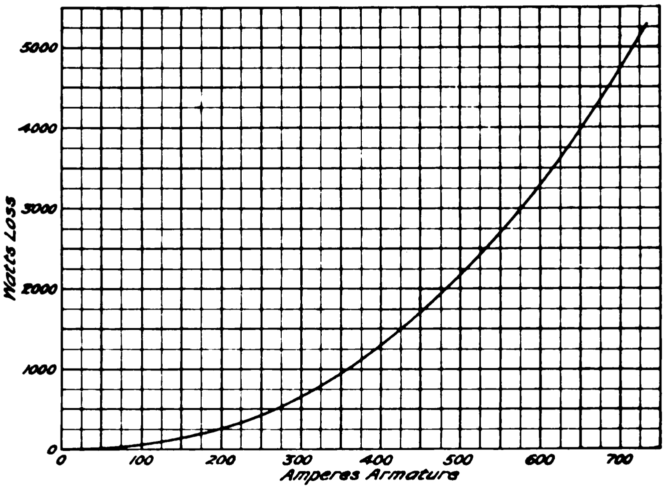


Fig 7. Short Circuit Core Loss on a 500 Kw., 600 Volt, 20 Pole, 360 R.P.M. 3-Phase, 60 Cycle, A.C. Generator

In order to insure constancy of friction losses during the entire test, the readings of the motor input for zero field should be repeated at least three times during the progress of the test; namely, at the beginning, again near the middle point of the curve, and lastly at the end of the test. Readings should also be taken at the end of the test with normal voltage field current and with brushes raised from the commutator, for comparison with the reading in which the same field was used with the brushes resting on the commutator, and with the set of readings giving the brush friction.

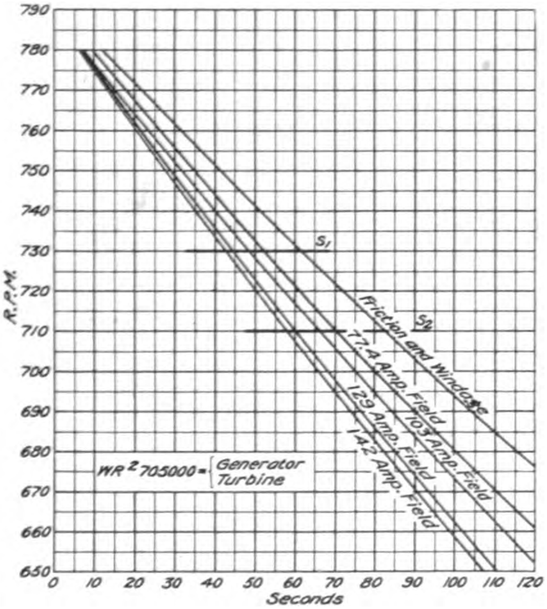


Fig. 8. Deceleration Curves on a 3000 Kw., 2300 Volt, 720 R.P.M 60 Cycle, 3-Phase, A.C. Generator

The tester should check these values, one against the other, to see that they are consistent, before turning in the results of the test. To check the results of the core loss as the test proceeds, the power input to the driving motor required by the core loss at a given excitation should be plotted against volts armature generated. This should give a curve similar to Fig. 6. If a satisfactory curve is obtained, the driving motor should be unbelted and a running free reading taken upon it, holding the same amperes field as were used during the test. The bearing friction and windage losses of the machine under test can be separated, if desired.

For a successful core loss test, all readings must be made at absolutely constant speed, when the rotating parts are neither accelerating nor decelerating. All values of field current must be held constant while taking readings. No pulsation or sudden variations must occur in the armature current of the driving motor, as these would vitiate the power readings.

In making out reports of core loss tests, the following data should be recorded in addition to the electrical readings already mentioned: Circumference of commutator; circumference of shunt and series field spools; height of shunt and series field spools; number and width of commutator bars; size and material of brushes; number of studs and brushes per stud; brush pressure per brush; rating of driving motor together with its armature and frame number; and the type, rating and number of the machine under test. On series motors core loss tests should be taken at several different speeds covering the range of the speed curve. The method used is identical with that described above, and will be considered in connection with railway and series motor tests.

Synchronous alternating machines generally have loss measurements taken on open circuit as outlined above, and also with the armature of the machine under test short circuited. In the latter case, the increase in power supplied by the driving motor over that required by the friction loss is plotted as ordinates against the amperes armature

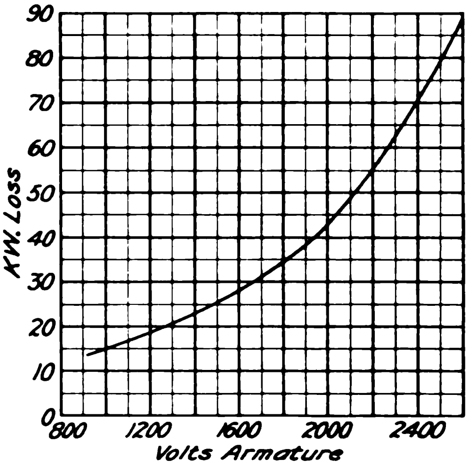


Fig. 9. Open Circuit Core Loss Curve taken from Deceleration Curves of Fig. 8.

as abscissæ or the open circuited armature voltage due to a given excitation. A curve is obtained similar in character to the open circuited core loss curve. Such a test is commonly known as "short circuited core loss." Fig. 7 shows the results of such a test after all correction factors have been applied. In making this test careful measurements must be made of the resistance of the short circuited armature circuit including all leads, before and after the test, since to obtain the true short circuited core loss, the C^2R loss must be subtracted. Observations should be made with the short circuited armature current at a value at least 200 per cent. of its normal full load current.

It is often necessary to determine the core loss, friction and windage losses of large machines when it is impracticable to employ the belted core loss method. The running light reading alone does not allow the separation of the core loss from friction and windage. A method known as the deceleration core loss is used for this purpose. Such tests are employed regularly on turbine-driven units, and it is often very convenient to use them in connection with certain vertical waterwheel-driven generators and other exceptionally large horizontal alternators and direct current machines possessing a considerable flywheel capacity.

A running light reading at normal speed and normal voltage should be taken to give the driving power necessary under that condition. Where this is not practicable, the moment of inertia of the rotating part must be known. This can be very accurately calculated for the majority of machines from their mechanical dimensions, as given by the working drawings. The test is as follows: First drive the machine with full field at a little above normal speed, and then suddenly cut off the driving power and observe the deceleration; then do the same thing with full field on the machine. In the first case the deceleration is due to the retarding force—to friction and windage,—and in the second case to these factors plus core loss. Readings of the speed of the rotating parts should be taken at sufficiently frequent intervals to obtain a uniform and reliable curve. A set of these curves is shown in Figs. 8 and 9. With the aid of these curves, together with a "running light" test or a calculation of the kinetic energy of the rotating parts, a determination of the value of the core loss, and also of the friction and windage, is readily make. The following is a brief derivation of the formulæ used in calculating such results by either method.

If M = mass.
W = weight.
v = linear velocity at radius of gyration.
ω = angular velocity.
S = speed r.p.m. corresponding to angular velocity.
g = 32.2 ft. per sec. per sec.
r = radius of gyration.
Wr^2 = flywheel effect.
E = power at speed s and time T
E_1 = power at speed S_1 and time T_1
E_2 = power at speed S_2 and time T_2

Then $\frac{E_1+E_2}{2}$ = average power from T_1 to T_2

The kinetic energy of a rotating body at any instant is equal to $\frac{1}{2}Mv^2$

$$\tfrac{1}{2}\,Mv^2 = \frac{W}{2g}\,v^2 = \frac{W}{2g}\,(r\omega)^2 \text{ where } \omega = \frac{2\pi s}{60}$$

The energy consumed in decelerating from

$$\omega_1 \text{ to } \omega_2 = \frac{Wr^2}{2g}(\omega_1{}^2 - \omega^2{}_2) = .00017\,Wr^2\,(S_1{}^2 - S_2{}^2)$$

foot pounds.

Since the average power during the interval multiplied by the time required to decelerate from S_1 to S_2 is equal to the energy loss in decelerating from S_1 to S_2,

$$\frac{E_1+E_2}{2}\,(T_2 - T_1) = .00017\,Wr^2\,(S_1{}^2 - S_2{}^2) \text{ or}$$

$$E = .00017\,\frac{Wr^2\,(S_1{}^2 - S_2{}^2)}{T_2 - T_1} \text{ ft. lbs. per sec.}$$

$$\text{Therefore, kw.} = \frac{0.00017\,Wr^2\,(S_1{}^2 - S_2{}^2)}{T_2 - T_1} \times \frac{746}{550} \times \frac{1}{1000} = \frac{2308}{10^{10}} \times \frac{Wr^2\,(S_1{}^2 - S_2{}^2)}{T_2 - T_1}$$

If T_3 and T_1 are respectively the times at which the speeds S_1 and S_2 occur with no field on the machine, then kw. in this case =

$$\frac{2308}{10^{10}}\;\frac{Wr^2\,(S_1{}^2 - S_2{}^2)}{T_1 - T_3}$$

The kw. core loss is then the difference between the kws. obtained by the formulæ given above.

If the kw. running light has been obtained.

$$\text{kw. running light} = \frac{2308}{10^{10}}\;\frac{Wr^2\,(S_1{}^2 - S_2{}^2)}{T_2 - T_1} = K\,\frac{Wr^2 (S_1{}^2 - S_2{}^2)}{T_2 - T_1}$$

$$\text{Therefore } Wr^2 = \frac{\text{kw. running light } (T_2 - T_1)}{K\ (S_1^2 - S_2^2)}$$

$$\text{Also kw. friction} = \frac{K\ Wr^2\ (S_1^2 - S_2^2)}{T_4 - T_3}$$

$$\text{Kw. Loss} = \frac{2308}{10^{10}} Wr^2 \frac{(S_1^2 - S_2^2)}{T_2 - T_1}$$

$$= \frac{2308}{10^{10}} \times \frac{705000 \times 28900}{20.8} = 226$$

TABLE IV

Deceleration Core Loss

Amps. Field Held	T_1	T_2	$T_2 - T_1$	S_1	S_2	$S_1^2 - S_2^2$	Friction	Core Loss and Friction	Core Loss	Volts from Saturation
0	61.6	82.4	20.8	730	710	28000	226	226	0	0
77.4	52.1	70.6	18.5	730	710	28000	226	254	28	1570
103	48.2	66.1	17.9	730	710	28000	226	266	40	1990
129	44.4	60.5	16.1	730	710	28000	226	292	66	2350
142	42.8	58.2	15.4	730	710	28000	226	306	80	2500

Or substituting for Wr^2

$$\text{Kw. friction} = \frac{T_2 - T_1}{T_4 - T_3} \times \text{kw. running light.}$$

Hence knowing "running light," the friction can be calculated and the core loss separated from the "running light."

In making "deceleration core loss" tests, the same data should be recorded that are required in connection with the "belted core loss" method. Tables II and III show the standard method of calculating test results, open circuited and short circuited, taken by the "belted core loss" method. Table IV shows the method employed in calculating results of "deceleration core loss" by using either the value of the moment of inertia of rotating parts, or by "running light" test.

Calculations of Deceleration Core Loss on a 3000 Kw., 2300 Volt, 10-Pole, 60 Cycle, 3-Phase Generator

Moment of inertia is equal to 705,000.

The normal speed of the turbine being 720, S_1 is taken equal to 750 and S_2 equal to 710.

First curve (top), Fig. 8, taken with no field on the machine.

T_1 or time corresponding to $S_1 = 61.6$ seconds.

T_2 or time corresponding to $S_2 = 82.4$ seconds.

$T_2 = 82.4$	$S_1^2 = 532900$
$T_1 = 61.6$	$S_2^2 = 504000$
Diff. = 20.8	28900

Substituting these values in formula

Second curve, taken with 77.4 amperes field current.

$T_2 = 70.6 - T_1 = 52.1 = 18.5$

$$\text{Kw. Loss} = \frac{2308}{10^{10}} \times \frac{705000 \times 28900}{18.5} = 254$$

Third curve, taken with 103 amperes field current.

$T_2 = 66.1 - T_1 = 48.2 = 17.9$

$$\text{Kw. Loss} = \frac{2308}{10^{10}} \times \frac{705000 \times 28900}{17.9} = 263$$

Fourth curve, taken with 129 amperes field current.

$T_2 = 60.5 - T_1 = 44.4 = 16.1$

$$\text{Kw. Loss} = \frac{2308}{10^{10}} \times \frac{705000 \times 28900}{16.1} = 292$$

Fifth curve, taken with 142 amperes field current.

$T_2 = 58.2 - T_1 = 42.8 = 15.4$

$$\text{Kw. Loss} = \frac{2308}{10^{10}} \times \frac{705000 \times 28200}{15.4} = 306$$

From the saturation curve the volts armature corresponding to the various field currents used can be obtained and a core loss curve plotted between volts armature as abscissæ and core loss as ordinates.

Field Compounding

Field compounding tests determine the additional ampere turns field necessary to overcome armature reaction and CR drop in a machine from no load to full load. The test is made by separately exciting the field of the machine under test, in order to hold the voltage at the armature terminals constant as the load is increased from no load to full load. Readings of amperes field, volts field, amperes armature, volts armature, and speed are taken at no load and at least three intermediate points between no load and rated load. It is generally required and usually advisable to take an observation at 25 per cent. overload, if the power is available. All readings should be made with a rising field current. On polyphase apparatus the phases should be loaded equally so that their currents will be properly balanced. Fig. 10 shows a curve of field compounding in which amperes field or ampere turns are plotted as ordinates and amperes armature as abscissæ. This curve is plotted to the values given in Table V.

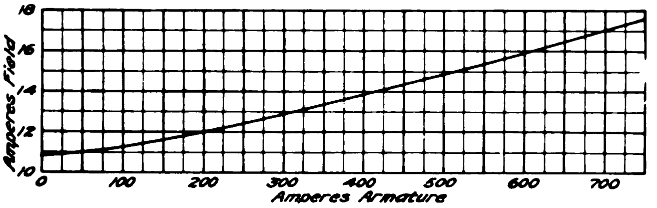


Fig. 10. Field Compounding Curves on a 150 Kw , 250 Volt 225 R.P.M., 6-Pole, D.C. Generator, (6 Bar Brush Shift)

Maximum Output

The maximum output of direct current compound wound generators is dependent upon their commutation, or heating limitations; hence the maximum output test on these machines is usually a commutation test, which will be described later. Since in shunt wound generators the voltage falls with the load at constant field excitation, the maximum output is not always limited by commutation. It is not usual to make maximum output tests, however, on compound wound machines, since they possess little practical interest.

TABLE V

Field Compounding on a 150 Kw., 250 V., 225 R.P.M., 6-Pole, D.C. Generator

(6 Bar Brush Shift)

Volts Arm.	Amps. Arm	Volts Field	Amps. Field	R.P.M.
250	0	226	10.8	225
250	150	240	11.65	225
250	300	270	12.90	225
250	450	300	14.3	225
250	600	334	15.9	225
250	750	370	17.6	225

In the case of induction motors, the maximum output, or breakdown point, is a matter of considerable importance. If sufficient power is available, the motor is loaded in successive steps up to the breakdown point, beginning at zero load. During this test readings of volts armature, amperes armaature, speed, and motor output are taken and plotted. It is essential that the voltage and frequency of the power circuit from which the motor is operating be held constant. It is also important that readings be taken quickly at overload currents, and that the motor be allowed to cool between such readings, else it will overheat. Where sufficient power is not available to take a breakdown test with normal voltage impressed on the armature of the motor, a voltage considerably below normal is used; *viz.*, ¾, ½, or even ¼ voltage. It is then necessary to calculate the full voltage results from those obtained at the lower voltages. This may be done by increasing the power output in proportion to the square of the ratio of normal voltage to the lower voltage.

The load at which a synchronous motor breaks from synchronism when operating at its normal rated voltage and frequency is often necessary. All maximum output tests on synchronous motors, unless stated to the contrary, should be made with a field excitation giving minimum input armature current for a given load. Readings must therefore be taken of volts armature, amperes armature, amperes field and volts field, with various loads from no load to that load which will cause the motor to break from synchronism, the field strength being adjusted for each reading to give minimum input. The speed of a synchronous motor will be constant until the point of breakdown is reached, whereas that of an induction motor will decrease from no load to the breakdown point.

In case sufficient power is not available to make a maximum output test upon a synchronous motor at its normal rated voltage, its voltage may be reduced below normal, as described for induction motors. If the minimum input obtains when the readings are taken, the output of the motor at normal voltage may be determined in the manner described for induction motors.

The wiring for this test must be arranged so that the armature circuit of the motor can be opened immediately when the motor breaks from synchronism.

(To be Continued)

GASOLENE-ELECTRIC GENERATING SETS

By F. C. Barton

Introductory

Life in the country, either at the country residence or on the farm, is too often marred by annoying inconveniences, such as poorly lighted houses, inadequate water supply, and the lack of many comforts which in city life come as a matter of course. Electricity has supplied country residents with the telephone for communication and the trolley car for transportation, and two important developments recently made assure many additional conveniences to the country home and the farm. The first of these is the perfection of a gasolene-electric generating set having the reliability and serviceability of a high grade locomotive or the finest Corliss engine, and the second is the invention of a new type of incandescent lamp, which is as much superior to the former type as gas was superior to tallow dips.

With a gasolene-electric generating set and tungsten lamps, the country gentleman or the progressive farmer who now has no electric service available can provide electric lighting equal in every respect to the lighting ordinarily supplied in towns and cities, and can also develop electric power for a surprisingly large number of useful applications, such as pumping water, vacuum cleaning, electric heating and cooking, and for operating electric fans, sewing machines, elevators, laundry machinery, refrigerating plants, and all kinds of farm machinery.

Advantages of Electricity

No argument is necessary to prove the convenience of electric light which is instantly available in the house, barn and garage or on the driveway, by the turn of a switch, but there are advantages inherent in the electric system just as important as convenience, if not so apparent. Among them may be mentioned safety, flexibility and great variety of utility.

With the limited protection usually available in rural districts, fire if started is liable to be disastrous to life and property and every possible precaution should be used to prevent it. There are perfectly logical reasons for excluding oil lamps, all gas generating systems, and even candles from the country residence. Electricity, on the other hand, not only minimizes fire risks by eliminating flame, but in the electric pump it furnishes a wonderfully effective means of fighting fire.

No power can be transmitted so readily as electricity. An electric light or an electric motor can be installed in any place where it can be connected by wire to the generator. The farm or country estate equipped with an electric plant can thus have electric light and electric power available in every building and throughout the grounds.

The principal uses of electricity have already been mentioned, but are referred to in more detail in the following paragraphs.

Lighting

Electricity furnishes the safest, cleanest, most effective, and most convenient system of lighting obtainable. Electric lamps consume no oxygen and therefore do not vitiate the air. They require no matches and burn without flame; therefore they are safe. They are turned on and off by means of a switch placed in the most convenient location. The electric system is not affected by extremely cold weather as in the case of gas. The tungsten lamp gives almost three times the amount of light obtainable from the old type of lamp with the same current, and the quality of the light is much superior. While it is almost pure white, it does not produce the ghastly appearance noticeable with gas mantles or acetylene. The tungsten lamp is one of the important factors in this system because it reduces the power required for lighting to one-third the former amount, or enables three times as much light to be obtained for the same power. Arc lamps may also be connected to the circuits if desired.

Motors

Electric motors operated from the generating set can be used to drive domestic and farm appliances. Among these applications may be mentioned:

Pumps

The convenience of a plentiful supply of water under pressure for the maintenance of lawns and gardens and for fire protection, as well as for household use, will readily be appreciated. In a motor driven pump, the inconvenience and uncertainty of wind or other power is absent and the pump may be controlled automatically; *i.e.*, the motor may be started by an automatic device when the level in the storage tank reaches a predetermined low point and automatically stopped when the tank is full.

Vacuum Cleaners

The vacuum process of household cleaning is now almost indispensable and either the portable cleaner or the larger permanent installations may be readily operated by motors deriving their power from a gasolene-electric generating set.

Elevators

Electric freight or passenger elevators may be operated noiselessly and with perfect safety.

Laundry Machinery

Electricity is ideal for operating washing machines, wringers, and mangles. Such machines when operated electrically will do double the work of similar machines hand operated.

Refrigerating Plants

Domestic refrigerating plants electrically operated are now successfully used to maintain a cold storage room and furnish pure ice.

Domestic Appliances

Motors are available for operating sewing machines, coffee grinders, buffing wheels for polishing silverware, emery wheels for sharpening knives, and a variety of other labor saving appliances.

Fans

Motor driven cooling or ventilating fans may be used to particular advantage in the kitchen and laundry, and small portable fans may be attached to the circuit at any point.

Heating and Cooking

The general heating of buildings by electricity is not recommended, but effective electric heaters are supplied for temporary or auxiliary heat in the bath room, library, nursery, etc. They are particularly convenient at the seasons of the year when it is too cold to be without some heat, but not cold enough to light the furnace fire. Especial attention is called to the direct heat which is available in the circulating system of gasolene-electric sets. By means of suitable piping this heat may be used for warming the garage, greenhouse or other buildings.

Electric cooking and ironing are now entirely practicable and a number of devices of surprisingly great utility and variety have been developed. Among them may be mentioned the electric flatiron, water heater, broiler, combination cooker, frying pan, grid, oven, disk stove, tea kettle, chafing dish, percolator, toaster, and cigar lighter.

Farm Machinery

The flexibility of the electric system makes it particularly desirable for driving farm machinery.

Feed cutters, harvesting machinery, and creamery appliances can be operated with less personal danger and with no risk of fire where electric motors are employed.

Automobiles and Launches

Gasolene-electric generating sets furnish an abundant supply of current for charging directly the batteries of electric automobiles and launches, and the ignition batteries of gasolene driven vehicles.

All of these useful applications of electricity and many others become immediately available when a gasolene-electric generating set is installed.

Cooling System for Gasolene-Electric Generating Sets

The engines and generators comprising the sets offered by the General Electric Company are not purchased from different manufacturers, but are built and designed by the Company for operation as complete units. The engines of all sets are water cooled, and the best arrangement to adopt in the application of this method will depend so largely upon local conditions that it cannot be positively stated until those conditions are known.

The principal methods of applying water cooling are as follows:

(*a*) Where the amount of water available is limited, the water may be cooled by a motor-driven blower set forcing air through a gilled tube radiator. (See Fig. 1.) The motor driving this fan for the 25 kilowatt set consumes about 2½ kilowatts, and for the 10 kilowatt set about 1½ kilowatts. This is the standard equipment which is furnished on the sets for the U. S. Army. The amount of power consumed by the motor should not be deducted from the nominal generator rating, as the sets are rated at 25 and 10 useful kilowatts respectively available at the switchboard. In this system loss of water is negligible, as there is practically no evaporation.

(*b*) As a possible modification of this system, the use of a cooling tower with an expansion tank at the top is suggested, the heat being radiated from a large number of turns or loops of iron pipe around which the air is allowed to circulate freely, and through which water is propelled by the gear pump furnished with the engine. (See Fig. 2.) The amount of pipe required would depend largely upon the atmospheric temperatures to which it is exposed, and also its location; it is almost impossible to give definite figures unless the conditions in individual cases are known.

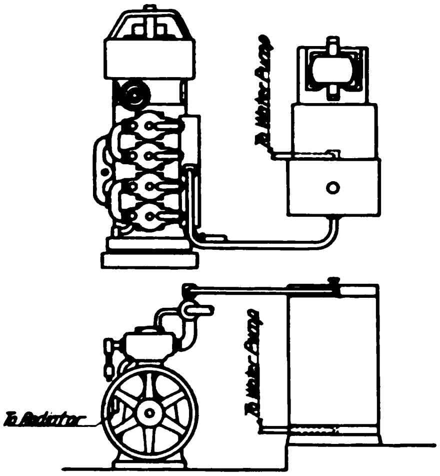


Fig. 1

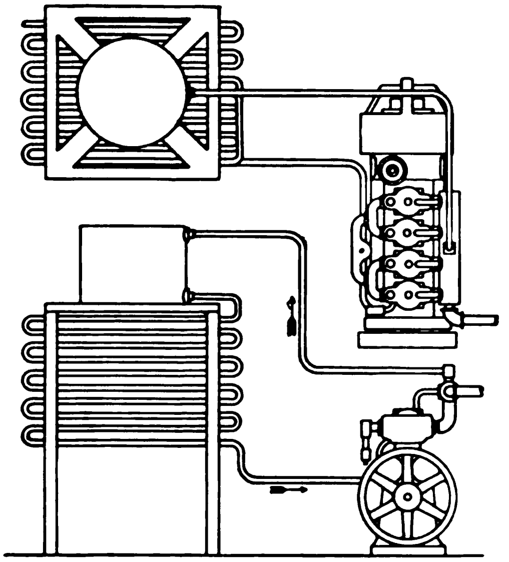


Fig. 2

Where a constant supply of cold water, at pressure, is available, radiating apparatus is unnecessary. The water connections are then as shown in Fig. 3.

The amount needed to cool the engine under these conditions will be approximately 7 gallons per minute when operating at full load for the 25 kw. set and proportionately less for the smaller sets if the temperature of the water is below 18 degrees centigrade.

A modification of this method, recommended as being superior, makes use of a cylindrical tank of approximately 4 ft. diameter by 6 ft. high, mounted approximately on a level with the engine, or perhaps a little above it. (See Fig. 4.) A pipe leading to the engine enters close to the bottom of the tank, and the outflow from the engine enters the tank near the top, the circulation being maintained by the gear pump on the engine. As this tank would not in itself dissipate all of the heat conducted from the engine jackets, a constant flow of cold water should be admitted at the lower part of the tank, the excess being permitted to overflow into a waste pipe. The advantage of this method lies in the fact that rapid circulation of water in the engine jackets is permitted with comparatively small increase in temperature between the incoming and outgoing water at the engine.

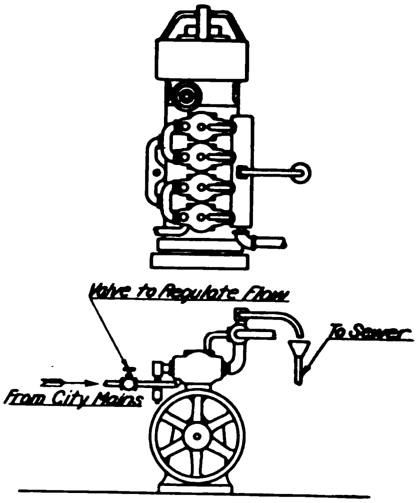


Fig. 3

Where it is undesirable to use the motor-driven fan and where water is scarce, a battery of tanks may be used, and circulation through them maintained by the gear pump on the engine. (See Fig. 5.) If this method is employed, for the 25 kw. set 5 tanks 4 ft. 6 in. x 8 ft. high will be needed, 3 tanks will take care of the 10 kw. set, it being understood that these tanks will be so set that there will be a free circulation of air around them. This method is subject to modification by the use of a single tank, but this in the case of the 25 kw. set is scarcely feasible, owing to the large dimensions of the tank which would be necessary.

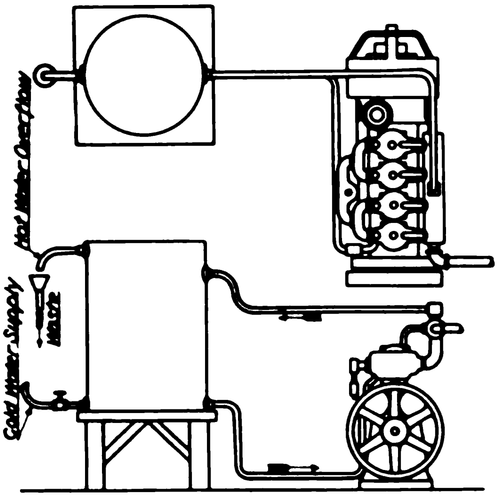

Hot Water Overflow
Cold Water Supply
Waste

Fig. 4

Where the engine is no more than 6 ft. above the level of the water, as in the case of a pond, lake, creek or the ocean, the water may be lifted directly by the gear pump on the engine and discharged from the jackets into a waste pipe. (See Fig. 6.)

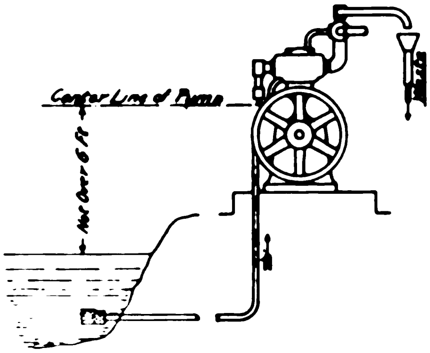

Center Line of Pump
Not Over 6 Ft
Waste

Fig. 6

Where the lift is over 6 ft., and auxiliary motor-driven pump may be located nearer

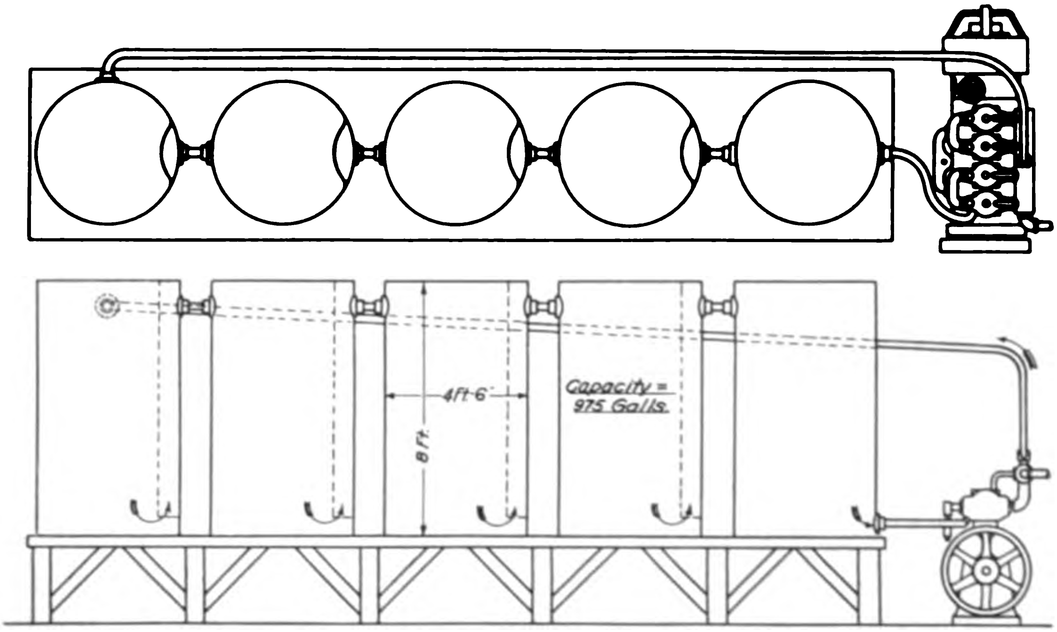

4 ft 6
8 Ft.
Capacity = 975 Galls.

Fig. 5

the level of the water, and the delivery pipe from the pump lead directly to the engine jackets, overflowing into a waste pipe. (See Fig. 7.)

The auxiliary pump may be eliminated by using a submerged coil of pipe, the top of which is connected to the discharge pipe on the engine, and the lower end to a small expansion tank located on a level with the engine, or a trifle above it; another pipe from this tank leads to the gear pump on the engine. (See Fig. 8.) In this method the height of the engine above the water does not affect the operation of the gear pump, as it is practically a closed and balanced circulating system. If the set is subjected to temperatures below freezing point, the addition of alcohol or other non-freezing solution to the circulating water will, at small cost, eliminate freezing troubles.

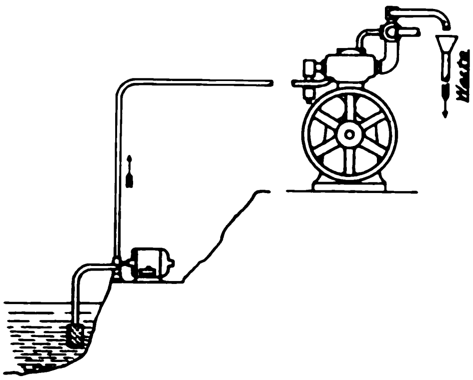


Fig. 7

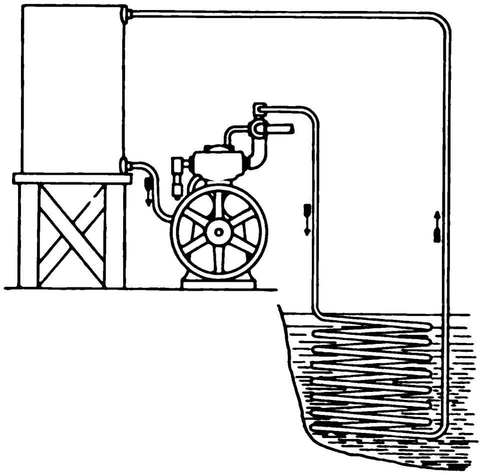


Fig. 8

Fuel Economy and Thermal Efficiency of Gasolene-Electric Generating Sets

Designed originally for the United States Government, for long continued and rigorous duty in sea-coast fortification; all parts of

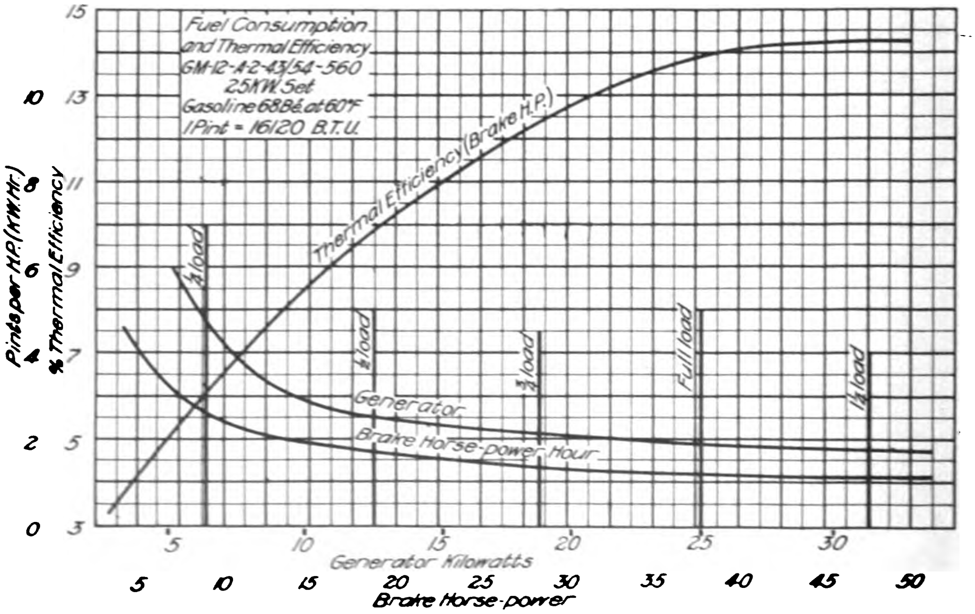


Fig. 9

the engine and generator have the greatest possible margin for safety, and the cylinders and valves are of such a size that the total output may be taken from the generator without a possibility of the overheating of either cylinders or valves. This liberality in design also permits the engine to deliver loads greater than those for which they are rated. Overloads are not guaranteed, but it will be found that they can be carried when occasion makes it necessary.

Fig. 9 shows a characteristic fuel consumption curve, as taken from an average 25 kw. set; better results are frequently obtained. The economy of the smaller sets is correspondingly high. Figs. 10 and 11 show reduction which must be made in the ratings where these sets are installed in high altitudes.

Domestic Heating from the Circulating System of Gasolene-Electric Generators

With the steam engine, coal is burned under a boiler, and the products of combustion pass up the stack in the form of smoke and hot gases, and, in so doing, produce a draught, which is necessary in order that further combustion may take place under the boiler. With the gas engine, no draught is necessary, and the products of combustion are expelled through an exhaust pipe. The gases expelled are much less in volume, but much hotter than those from a boiler.

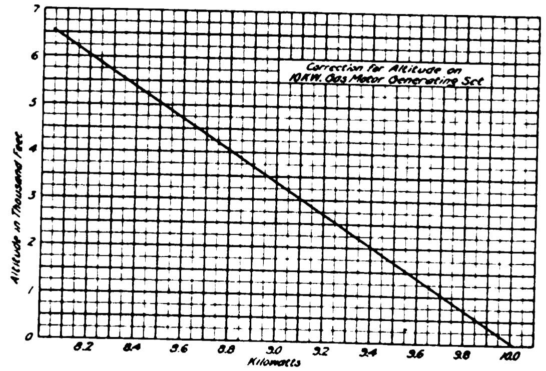


Fig. 10

Owing to the small volume of the gas, its high temperature, and the fact that it is expelled from the engine under pressure, it can be very advantageously used for domestic heating. In addition to the heat in the exhaust gases, there is also the heat conveyed from the cylinder walls by means of the circulating water used in cooling the engine cylinders. This heat also may be rendered available for heating purposes. The use of one or the other of these sources of heat, or a combination of the two, in a domestic heating appliance developed by the General Electric Company, will furnish an abundant supply of hot water for laundry or for heating the garage, greenhouse or other nearby buildings to which the set supplies electricity.

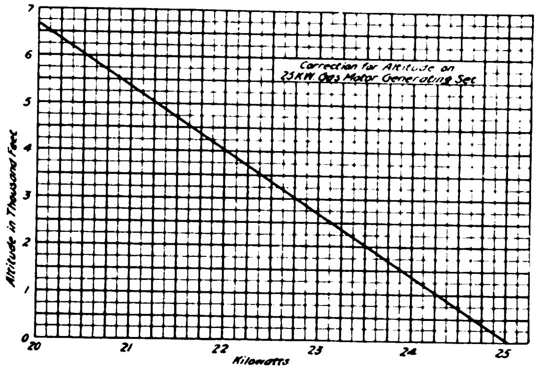


Fig 11

This apparatus constitutes a hot water heating system drawing its heat from the exhaust gas or circulating water, or both. It provides for a large amount of heat storage, which makes possible the shutting down of the set for a number of hours without inconvenience. This device will operate in multiple with any standard hot water house heating system. Therefore, in case it becomes necessary or desirable to stop the gasolene engine for a greater period of time than can be covered by the stored heat, the ordinary domestic hot water system can be started without any changes whatever.

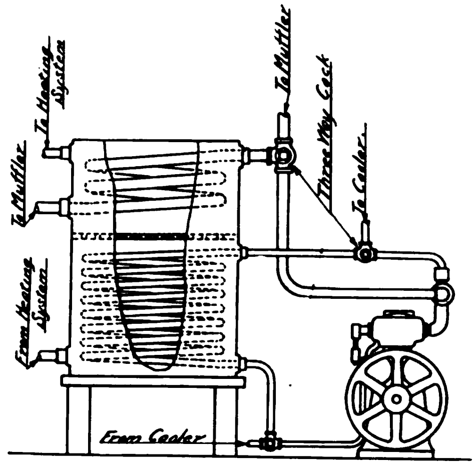


Fig. 12

TRANSMISSION LINE CALCULATIONS

Part III

By Milton W. Franklin

Inductive Reactance

It was shown in equation 13 *et seq*, of part II, that the e.m.f. of self-induction may be expressed as the product of the *coefficient of self-induction* by the *rate of change* of the current. Thus, if the value of L is known for the whole line and also that of $\frac{dC}{dt}$, the product of these two quantities will give the value of the e.m.f. of self-induction for the whole line. The value of L is obtained from the tables by multiplying the tabulated value by the number of times a length of 1000 ft. is contained in the length of the whole line, the value of $\frac{dC}{dt}$ being taken as its root mean square.

$$e_L = L\left(\frac{di}{dt}\right) \qquad (1)$$

but

$$i = I_m \sin(\omega t) \qquad (2)$$

$$\frac{di}{dt} = \omega I_m \cos(\omega t) \qquad (3)$$

$$= \omega I_m \sin\left(\frac{\pi}{2} - \omega t\right) \qquad (4)$$

$$e_L = \omega L\, I_m \sin\left(\frac{\pi}{2} - \omega t\right) \qquad (5)$$

This is seen to be itself a harmonic function, the effective value of which is obtained by finding the area of one lobe of the curve

$y = [I_m \sin(\omega t)]^2$ . . . .

and dividing this by the length of the base $\frac{\pi}{2}$.

$$E_L = \omega L \sqrt{\frac{2 I_m^2}{\pi} \int_0^{\frac{\pi}{2}} \sin^2\left(\frac{\pi}{2} - \omega t\right) dt} \qquad (6)$$

$$= \omega L \sqrt{\frac{2 I_m^2}{\pi} \left[\frac{\frac{\pi}{2} - \omega t}{2} - \frac{1}{4} \sin 2\left(\frac{\pi}{2} - \omega t\right)\right]_0^{\frac{\pi}{2}}} \qquad (7)$$

$$= \omega L \sqrt{\frac{2 I_m^2}{\pi} \left[0 - \left(\frac{\pi}{2} - 0\right)\right]} \qquad (8)$$

$$= \omega L \frac{I_m}{\sqrt{2}} j \qquad (9)$$

where j is a constant. $= \sqrt{-1}$, and in this case indicates the direction of I_e;

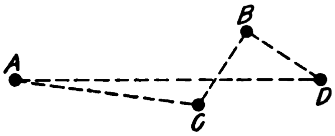


Fig. 6

but $\frac{I_m}{\sqrt{2}}$ is called the effective value of I and therefore (9) reduces to

$$E_L = -\omega L\ I_e, \qquad (10)$$

where I_e is the effective value of I.

$$\text{From (10)}\quad \frac{E_L}{I_e} = \omega L = X \qquad (11)$$

X is called the *inductive reactance* of the circuit. From equation (5) it will be seen that e_L lags behind the current i by the angle $\frac{\pi}{2}$, or by the time $\frac{T}{4}$ seconds, where T is the period or $\frac{1}{f}$.

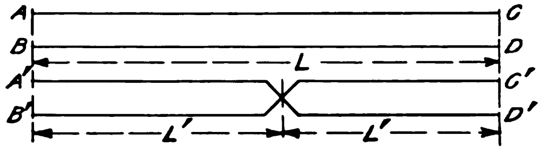


Fig. 7

When L is given in henries and I in amperes, E will be given in volts and X in ohms. Tables V and XIX of Transmission Line Constants (July and October issues of Review) give the inductive reactance per 1000 ft. conductor for a single-phase circuit with a frequency of 100~, for solid and stranded conductors, respectively. Tables III and IV (July REVIEW) give the values for solid conductors for 25~ and for 60~ respectively, and tables XVII and XVIII the values for stranded conductors. The values for any frequency may be found by multiplying the tabulated values by the factor $\frac{N}{100}$. Tables XI and XXV (August and December issues of REVIEW) give the inductive reactance per 1000 ft. per phase (loop formed by any 2 wires) for a three-phase circuit at a frequency of 100~, for solid and stranded conductors, respectively. Similar tables are given for 25~ and 60~ for solid and for stranded conductors.

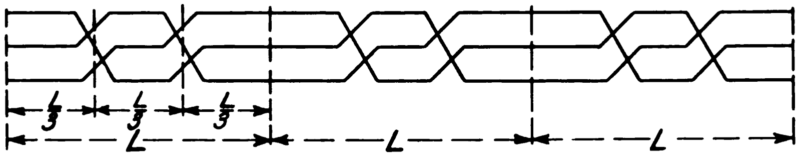


Fig. 9

Values for any frequency, N, are obtained by multiplying the tabulated values by the factor $\frac{N}{100}$.

Mutual Inductance (Transposition)

The effect of mutual inductance between two circuits is proportional to the interlinkage of the magnetic fluxes of the two lines. This in turn depends upon the proximity of the lines and upon the general relative arrangement of the conductors. The inductive effect of one line upon another is equal to the algebraic sum of the fluxes due to the different conductors of the first line, considered separately, which link the secondary line.

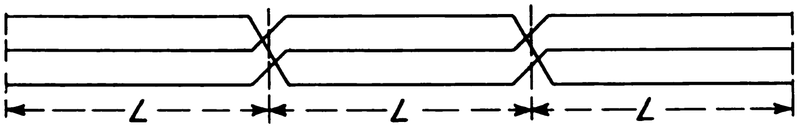


Fig. 8

The induction of a primary charged line upon a secondary line may be found from tables I and XV (July and September issues of REVIEW). The values of D are taken as the distance between the centers of the charged wires and each of the secondary wires severally considered. In Fig. 6, the induction due to A which links the circuit CD, is given by: (12)

$$2\,I\left[\left(ln\frac{AD}{r}+\frac{1}{4}\right)-\left(ln\frac{AC}{r}+\frac{1}{4}\right)\right]=2\,I\,ln\frac{AD}{AC}$$

Similarly that due to B is: (13)

$$2\,I\left[\left(ln\frac{BC}{r}+\frac{1}{4}\right)-\left(ln\frac{BD}{r}+\frac{1}{4}\right)\right]=2\,I\,ln\frac{BC}{BD}$$

The whole flux linked with the circuit CD due to the circuit AB is:

$$2\,I\left[ln\frac{AD}{AC}\pm ln\frac{BC}{BD}\right] \qquad (14)$$

The sign being determined by the relative positions of the conductors; *e.g.*, if C is nearer to both A and B than is D, then the fluxes must be added, and if *vice versa*, then (13) should be subtracted from (12).

In using tables I and XV, the values of the self-induction due to a spacing equal to AC, is subtracted from that due to a spacing equal to AD, which gives the induction due to A. In a similar manner the induction due to B is found.

The reactance; *i.e.*, voltage, may be found direct from tables III to XI and XVII to XXV on inductive reactance.

The effect of mutual induction is to induce surges in the line where a difference of frequency exists between the two currents, and to induce high electrostatic charges in lines carrying little or no current; *e.g.*, telephone lines.

This effect may be nullified by separating the lines and by transposing the wires of one of the lines so that the effect produced in one section is opposed by that in another. Of two parallel lines consisting of two wires each, one may be transposed to neutralize the mutual inductance. Fig. 7 shows this method. The length L' should be an even factor of L so that to every section of the line transposed there corresponds an opposing section.

Fig. 8 shows a scheme for transposing a three-phase line at the vertices of an equilateral triangle. The line is originally balanced and becomes unbalanced on transposing, a procedure which should be resorted to only to prevent *mutual induction*. A three-phase line with centers arranged in a straight line may be balanced by transposing as in Fig. 9.

(*To be Continued*)

THE SOUTHERN POWER COMPANY

By John Liston

The remarkable expansion which has recently characterized the industries of the South and which promises within a few years to restore to that section of the country a large share of its former commercial importance, is due to several factors, among which are a growing realization of the value of its agricultural products, notable improvements in transportation facilities, and the confidence of both local and northern capital in the permanent character of its new developments. In the last analysis, however, these various factors are found to be based to a large extent on the immense and hitherto practically undeveloped water resources of this section, which render possible the economical generation and distribution of electric power.

In no part of the South is this more demonstrable than in the Piedmont Cotton Belt, which covers the states of North and South Carolina and a portion of eastern Georgia. Running diagonally across this cotton belt, in a general direction north-west to south-east, is the Santee river drainage system (Fig. 1), with the tributaries of this river spread over a territory of approximately 15,000 square miles.

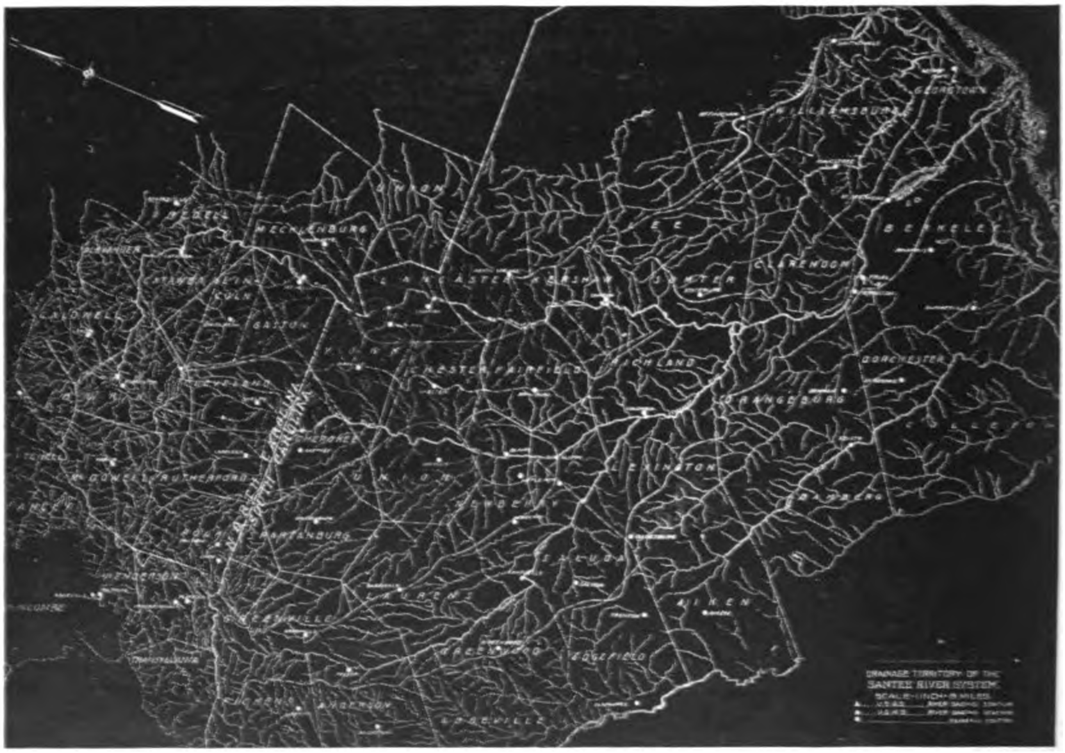

WILLIAMSBURG
GEORGETOWN
MECKLENBURG
LANCASTER
KERSHAW
SUMTER
CLARENDON
BERKELEY
CALDWELL
GASTON
YORK
CHESTER
FAIRFIELD
RICHLAND
DORCHESTER
ORANGEBURG
CHEROKEE
UNION
LEXINGTON
McDOWELL
RUTHERFORD
SPARTANBURG
NEWBERRY
SALUDA
HENDERSON
LAURENS
AIKEN
GREENVILLE
GREENWOOD
EDGEFIELD
ANDERSON
ABBEVILLE
NORTH CAROLINA
SOUTH CAROLINA
DRAINAGE TERRITORY OF THE SANTEE RIVER SYSTEM

Fig. 1. Drainage Territory of the Santee River System

Unlike the western rivers, the streams of the South do not afford high heads, but their great volume and the fact that their sources are to a large extent still heavily timbered, insures a dependable water supply throughout the year, while modern improvements in the efficiency of water wheels and generators, together with the recent developments in transmission and distribution systems, render it possible to obtain from the low and medium heads available, an amount of electrical energy which will afford cheap and ample power to local industries for many years to come. Within a radius of 60 miles from the city of Charlotte, N. C., there is water power sufficient to develop 1,000,000 electrical horse-power, and while a number of hydro-electric plants have been constructed in this territory there still remains a large field for future development.

The successful operation of the cotton mills of the Piedmont District is essential to its prosperity, as they constitute by far the most important industrial feature of this territory. The extent to which this statement applies is indicated by the following figures:

In North Carolina there are about 270 cotton mills, aggregating more than 3,000,000 spindles and using about 1,700,000 bales of cotton annually, while in South Carolina there are about 145 cotton mills, with a total in excess of 3,720,000 spindles and an annual consumption of about 1,500,000 bales of cotton; the total figures for the two states in 1908 being 412 mills, with 6,825,000 spindles, using more than 3,000,000 bales of cotton.

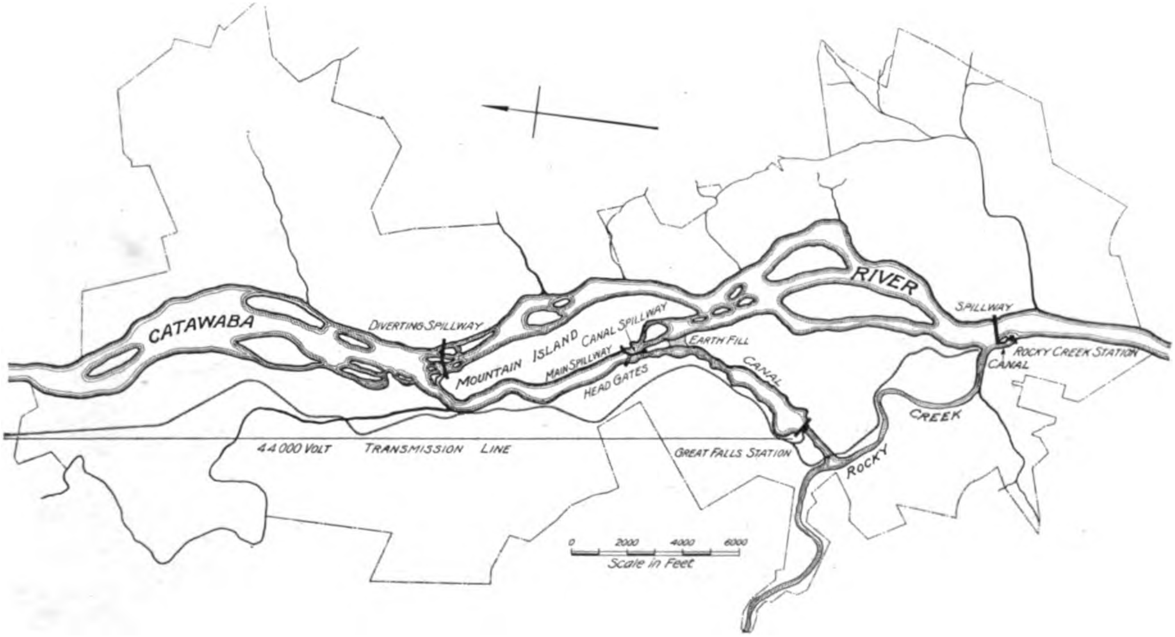


Fig. 2. Catawba River showing the Hydraulic Development of the Great Falls & Rocky Creek Power Stations

It was in this territory that the Southern Power Company acquired water power rights and started the construction of a series of hydro-electric plants that have proved of enormous benefit to the manufacturing interests of the Piedmont Cotton Belt. This article will describe briefly the work accomplished and projected, and in addition will indicate the impetus given to the industries of these states by the accessibility of a dependable power supply rendered possible by the numerous far reaching transmission lines of the Southern Power Company, which have an aggregate single circuit length of almost a thousand miles.

The Southern Power Company was organized in 1905 under the corporation laws of the State of New Jersey, its original capitalization of $7,500,000 being increased to $10,000,000 in 1906. The headquarters of the Company was established in the City of Charlotte, Mecklenburg County, North Carolina.

The bulk of the hydro-electrical development done by the Company has been along the course of the Catawba River, which is one of the tributaries of the Santee. This river rises on the eastern slope of the Blue Ridge; flowing first northeastward and then eastward, it bends abruptly to the southeast and flows in this general direction across the south-central part of North Carolina and the north-central part of South Carolina.

Throughout its course in North Carolina, and for a portion of its course in South Carolina above the mouth of Wateree Creek, the stream is known as the Catawba River; below Wateree Creek it is known as the Wateree River.

In a straight line, the total length of the stream is about two hundred and seventy miles, the distance along its winding course being about four hundred and fifty miles. The greater part of the drainage basin is hilly and a number of the tributary streams rise and flow for almost their entire course in a high mountainous country. About sixty-five per cent. of the upper portion of the drainage basin is forested and the average rainfall is about fifty inches, the total increasing as the stream is ascended.

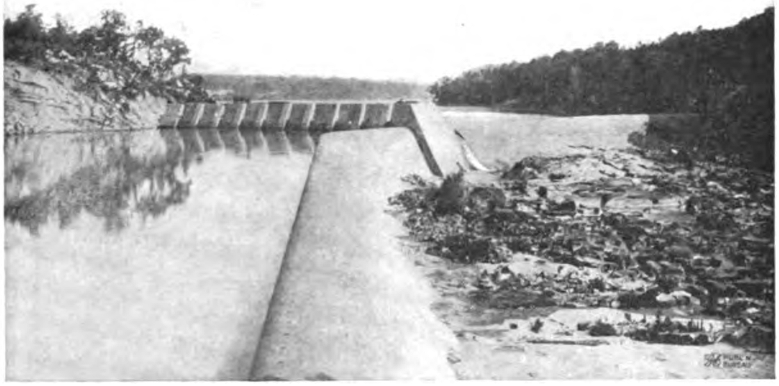


Fig. 3. View showing the Canal Intake, Canal Spillway and Main Spillway of the Great Falls Power Station

The first transaction of the Southern Power Company was the acquisition of the partially completed hydro-electric plant of the Catawba Power Company situated on the Catawba River about twenty-five miles southwest from the city of Charlotte. The drainage area back of this plant is about three thousand square miles, and the hydraulic development consists of a heavy masonry ogee section and overflow type dam 1,266 feet in length, with a spillway section of 585 feet. A portion of one of the shore ends of the dam is of the earth-filled masonry core type. The dam gives a normal operating head of twenty-five feet, backing the water up-stream a distance of more than twelve miles, with an average width of over 550 feet.

Due to the great amount of silt which is characteristic of the rivers in this section, only the higher levels of the stored water are available for power purposes, the pondage at the Catawba plant giving an average of thirty million cubic feet of water for each foot of the higher levels.

The maximum height of the dam from foundation to crest is about fifty-five feet, while its thickness at the base varies from forty to fifty-three feet; the foundations all resting on granite bed rock. The heart of the dam is made altogether of cyclopean masonry, the interstices being filled with concrete and the surfaces smooth finished with concrete. The power house, which is sealed in the rock of the river bank on one side, comprises part of the dam.

The machine equipment consists of four 750 kw., 300 r.p.m., 11,500 volt generators, and four 900 kw., 360 r.p.m., 11,500 volt generators. In each case these generators are located above their respective wheel pits, and are connected to the turbines by a rope

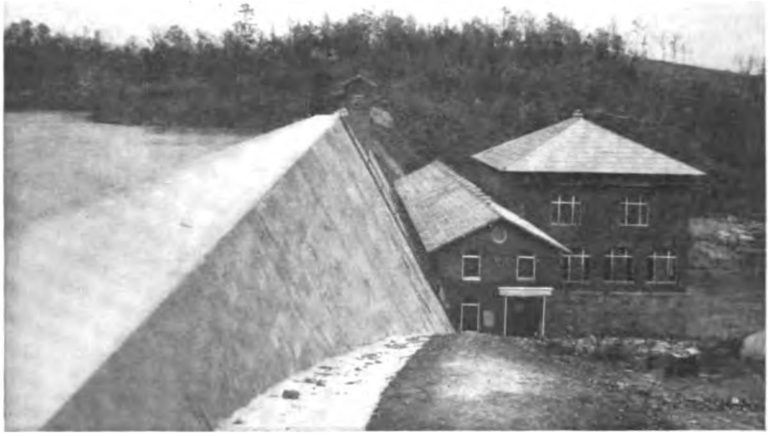


Fig. 4. Impounding Dam and Power House at Great Falls

drive system. This power house was originally intended to serve a territory within a radius of eighteen miles, but its transformer equipment is now so arranged that it can operate in multiple with the power houses of later construction which are located at the Great Falls of the Catawba River, about 30 miles south of the Catawba station.

The transformer equipment at Catawba consists of three water-cooled transformers of 2000 kw. capacity each, with 44,000 and 11,000 volt terminals. Current is received at the Catawba station from Great Falls at 44,000 volts, three-phase, 60 cycles, and is stepped down to 11,000 volts and connected through synchronizing oil switches to the Catawba station 11,000 volt bus-bars from which the feeder lines for the immediate territory are tapped.

The entire electrical equipment of this station, except the transmission lines, is of General Electric manufacture.

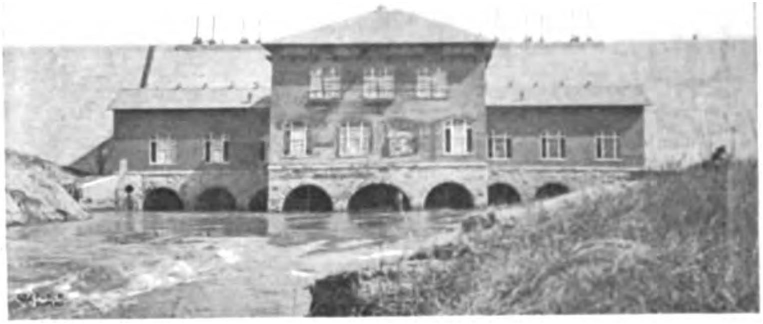


Fig. 5. Dam, Power House and Tailrace at Great Falls

The Great Falls of the Catawba River are located about 55 miles south of Charlotte, and consist of a series of falls and shoals extending for a distance of about 8 miles and giving a total drop of 176 feet. The topography of the country at this point rendered it inadvisable to attempt the development of the entire head in a single plant, and after careful preliminary work the Southern Power Company decided that the most thorough and economical development of the available power would involve the construction of three power stations. Two of these have already been constructed and are now in operation. The first one, known as the Great Falls Station, has one impounding and two diverting dams, and operates under a head of 69 feet, the drainage area back of the station being 4200 square miles. A reference to Fig. 2 should render clear the following explanation of this development.

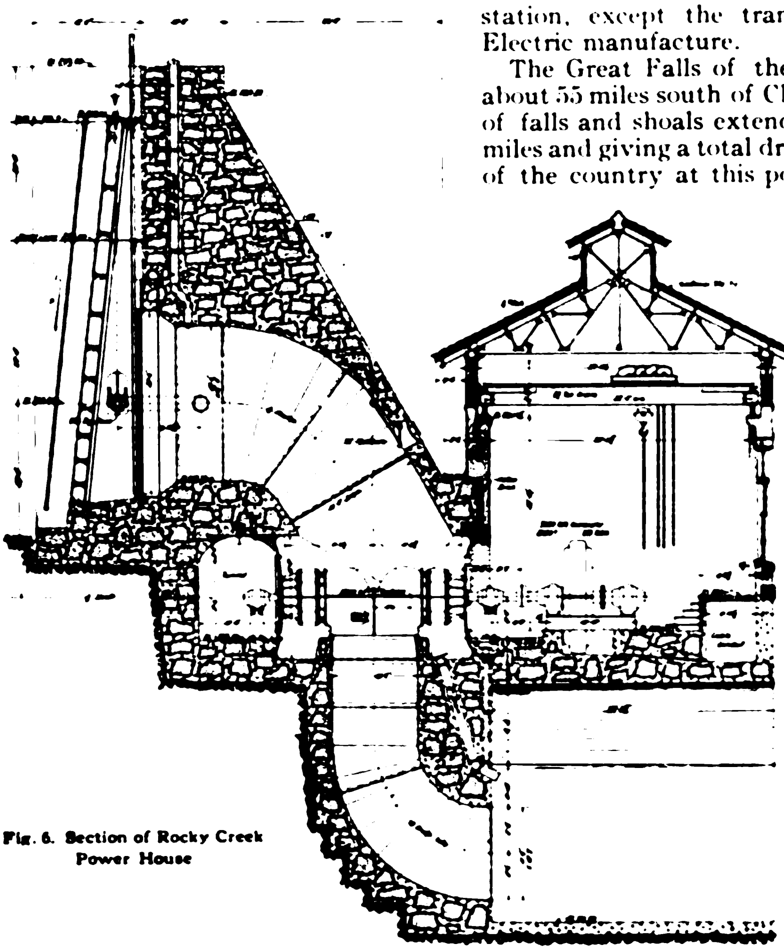


Fig. 6. Section of Rocky Creek Power House

About two miles above the power house there are numerous islands which divide the river into two main channels. At the head of

Mountain Island a low diverting spillway dam was constructed across the eastern channel of the river, crossing some small islands and shallow channels. It was only necessary to give the dam a height of between 7 and 8 feet from foundation to crest. About midway between this diverting spillway and the power house (Fig. 3), a second diverting spillway dam, canal headgate, and canal spillway were constructed across the west channel of the river. These works constitute the main spillway of the Great Falls plant, and the dam across the river at the power house is therefore not provided with a spillway section. The main spillway is about 440 feet long, its height being 30 feet, and the width of its base about 41 feet. At an angle of about 120 deg. from the main spillway, a canal spillway of 520 feet in length has been constructed, with an average height of 36 feet and a width at the base of 38 feet. At the head of this spillway is located the dam containing the headgates for the canal.

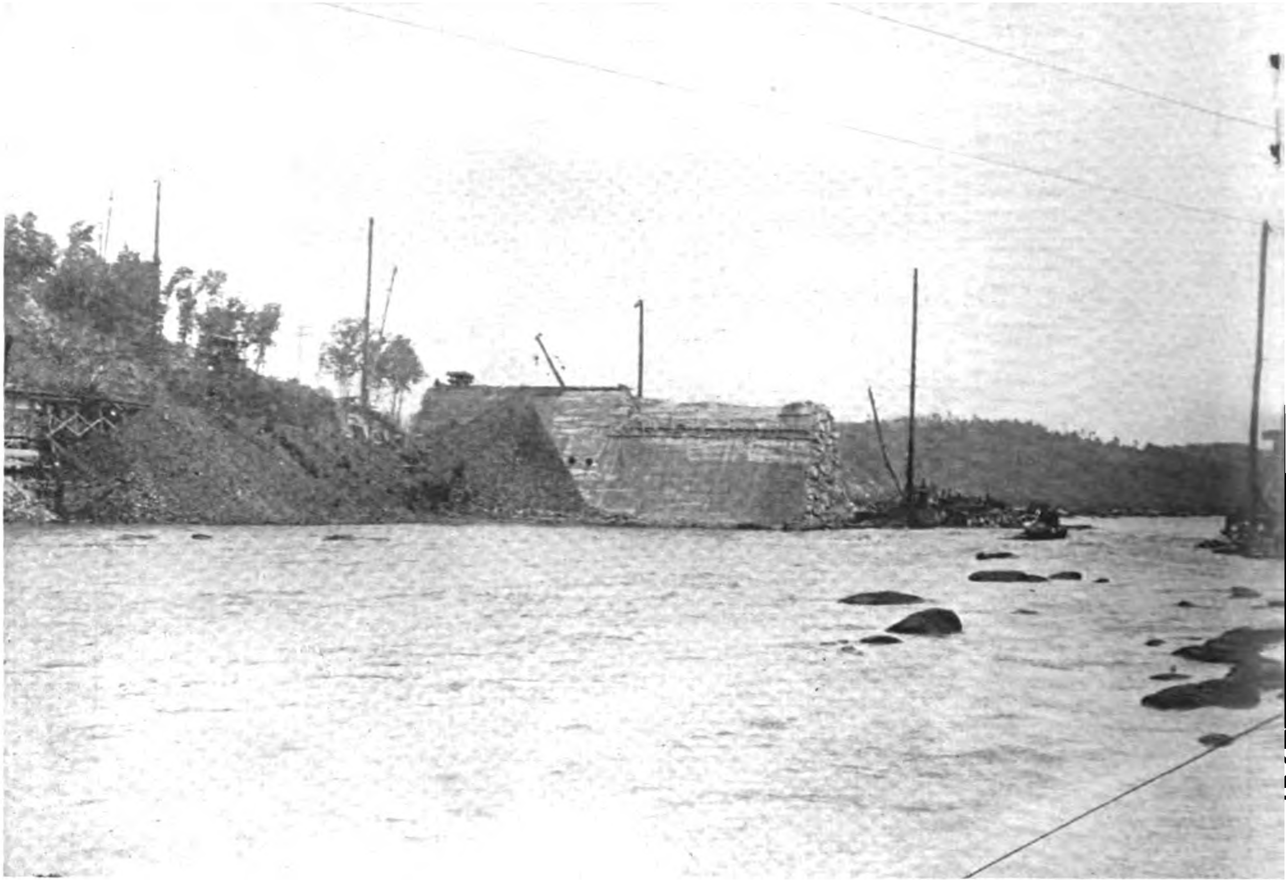


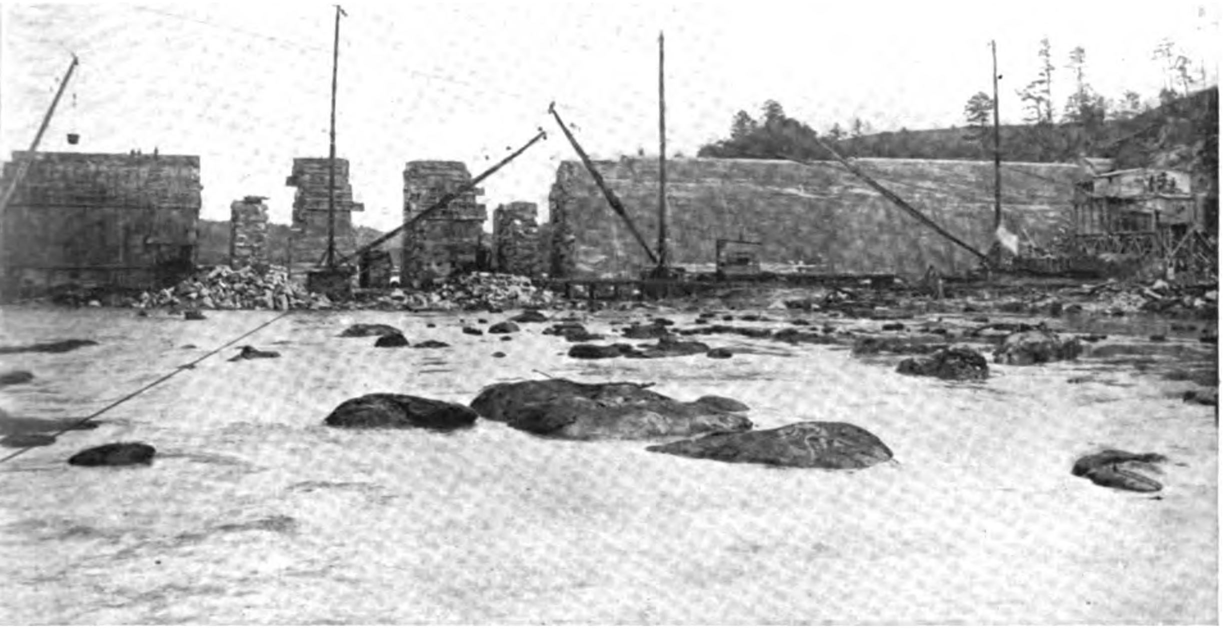
Fig. 7. Spillway Dam of the Rocky Cr

In order to carry the water from the headgates to the power house a canal 7250 feet in length was required, and it was found possible to utilize for this purpose a natural valley which ran for nearly the entire distance between the main spillway and the power house. Under these conditions it was necessary to excavate less than 200,000 cubic yards (part of this material being used in making an earth fill on the east bank) in order to provide a suitable canal for the entire distance.

The impounding dam at the power house, as stated above, is not provided with a spillway, and the power house itself (see Figs. 4 and 5) is located in the natural valley bed and forms a part of the dam. In adopting this form of construction the designing engineers have laid out the main and canal spillways so that the power house would be fully protected against any possible flood. The length of spillway provided up stream renders the power house immune from danger with 15 feet of water flowing over the crest of the dam.

The machine equipment of the Great Falls power house comprises ten turbine driven generators. Eight of these units consist of 5200 h.p. reaction turbines operating at 225 r.p.m. under a 69 foot head and driving eight 3000 kw., 2300 volt, three-phase, 60 cycle generators. The two remaining machines are exciter units, and are made up of 700 h.p. 450 r.p.m. turbines driving 400 kw., 250 volt exciters. Four banks of transformers, each consisting of three 2000 kw. water cooled units, are provided for stepping the current up to 44000 volts for transmission.

The tailrace of the Great Falls Power House leads directly into the bed of a small stream known as Rocky Creek, through which the water is conducted back to the channel of the river.



eek Station Under Construction

Just below the point where Rocky Creek enters the Catawba River and at a distance of about two miles south of the Great Falls station, the second power plant, known as the Rocky Creek station, has been constructed. This consists of a massive spillway dam (Fig. 7), extending across the river for a distance of 1000 feet, its height from foundation to crest averaging about 60 feet, and its width at the base being somewhat in excess of 70 feet. In the construction of this dam 130,000 cubic yards of masonry was laid, the entire development requiring the labor of 650 men for a period of two years.

Along the west bank of the river a canal 600 feet long and 80 feet wide at the bottom carries the water to the power house; the tailrace discharging directly into the bed of the river. The drainage area back of this power house is 4450 square miles, and a head of 63 feet is available under normal conditions, with the water backed up to the tailrace at Great Falls.

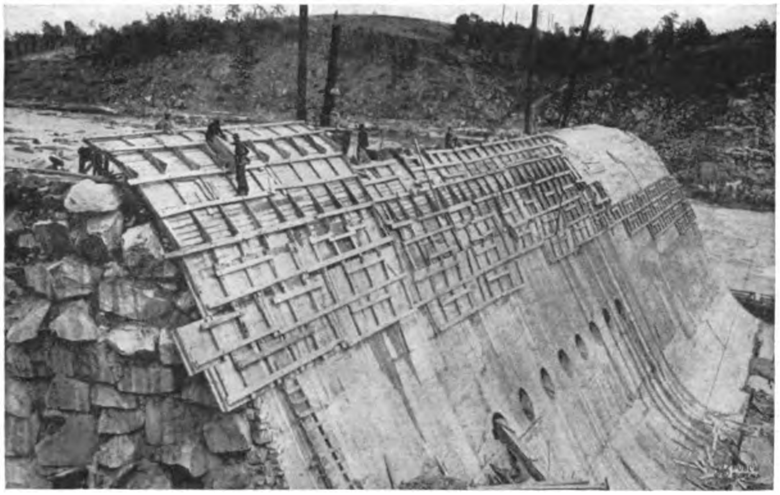


Fig. 8. A Section of the Rocky Creek Dam showing Cyclopean Concrete Construction

Eight 3000 kw. turbo-generator units have been installed, and the transformer equipment consists of twelve 2000-kw., three-phase, 60 cycle units. The current is generated at 2200 volts and stepped up for transmission to 44000 volts, the transmission line being tied in with that of the Great Falls and Catawba stations.

The electrical equipment of the Rocky Creek station practically duplicates that of the Great Falls station, except that motor driven generators are used for excitation. The general constructive features of both power houses are indicated by the sectional view of the Rocky Creek station shown in Fig. 6.

The construction of these dams is similar to that of the Catawba plant, all being made of cyclopean masonry (Fig. 8) utilizing stone of a size up to the limit of the capacity of the derricks used; many boulders weighing up to 15 tons being used in the Great Falls and Rocky Creek dams.

Owing to the lack of adequate transportation facilities it was necessary to construct 14 miles of standard gauge railroad for the transportation of machines and supplies. This work was done in the most thorough manner, and about 10 miles of the road now constitutes a part of the Seaboard Air Line railroad.

The Southern Power Company depends almost entirely on its hydro-electric plants for its supply of current, there being only one auxiliary steam plant in the system; this plant being of 1500 kw. capacity, and located in the city of Charlotte.

If we examine the water power resources of the Southern Power Company we find that at a conservative estimate they total 320,000 h.p. Of this total plans have been prepared for the development of 270,000 h.p., including those stations already completed and under construction.

The generator capacity of the Catawba, Great Falls and Rocky Creek stations amounts to 64,600 kw., and there is now nearing completion at 99 Islands, about 50 miles due west of Catawba, a power house which will develop 18,000 kw. This is located on the Broad River of the Carolinas, and utilizes a head of 72 feet.

Those power stations for which definite plans have been made, but which have not as yet been developed, are as follows:

Power Station	River	Available Head	Available H.P.
Lookout Shoals	Catawba	52 feet	8000
Mountain Island	Catawba	51 feet	10000
Landsford	Catawba	34 feet	13000
Fishing Creek	Catawba	50 feet	25000
Wateree	Wateree	80 feet	100000
Smiley Falls	Cape Fear	56 feet	10000
Haw River	Haw	....	6000

That the Southern Power Company has contributed materially to the development of the cotton mill industry in the territory served by its transmission lines is shown by the rapid growth of its connected load. When the Company was first organized the total power supplied was 1460 h.p., which was delivered to three cotton mills in one town. Today the connected load is approximately 70,000 h.p., and the service reaches 110 cotton mills in 42 cities and towns in North and South Carolina.

Many of the mills which changed over from mechanical to electric drive have enlarged their equipment, and 41 new mills have been designed especially for electric drive.

The progressive cotton mill operator is fully aware of the advantages of electric drive as compared with mechanical drive, and as soon as the transmission lines of the Southern Power Company were run, a large number of mill operators were found willing to discard their steam engine and boiler equipment and substitute electric motors. It has been found that in most installations where motor drive has been adopted, the steadiness in speed and the flexibility of motor drive has enabled the operators to speed up their machinery with a resulting increase in the volume of production for a given mill equipment. This increased production in most cases amounts to about 10 per cent. of the gross output.

Various methods of electric drive have been adopted; in some mills large motors are substituted for the discarded engines, in others the machinery is driven in small groups by motors, usually of less than 30 h.p. A four-frame drive has also been adopted, consisting of a motor provided with two double pulleys, one on either end of the shaft. The motor is usually mounted on the ceiling beams of the mill and drives four sets of frames by means of four belts. Some of the larger mills have adopted individual drive, supplying each unit of the machinery with its own motor.

A large percentage of the cotton mills of the Piedmont district are supplied with General Electric motors which have been especially designed to meet the conditions found in this industry.

At the present time the General Electric Company has installed in textile mills about 8000 motors, aggregating more than 185,000 h.p.; of these 727 motors with a total of about 22,000 h.p. are installed in mills on the Southern Power Company's system.

In addition to the cotton mills enumerated above, the Southern Power Company transmits power to various other industries in the territory covered by its system. In the city of Charlotte alone this distribution amounts to 2450 h.p., all supplied to small power users, none taking current in excess of 150 h.p. Before the advent of the Southern Power Company only 250 h.p. was used in Charlotte, the additions being largely due to the low power rates afforded.

Originally, many of the cities and towns on the transmission lines were not electrically lighted, but today 30 towns in North and South Carolina, with populations ranging from 1500 to 45,000, are lighted from the Southern Power Company's system. Of these 30 towns, 13 possessed electric lighting plants of their own, but found it more economical to abandon or sell them.

The extent of the service of this character is indicated by the following table:

CITIES AND TOWNS LIGHTED FROM SOUTHERN POWER CO'S SYSTEM

North Carolina

Name	Approx. Pop.	Name	Approx. Pop.
Pineville	3000	*Statesville	7000
Bessemer City	4000	*Concord	14000
Kings Mountain	5000	Kannapolis	2000
Cherryville	3000	China Grove	6000
Lincolnton	6000	Dallas	2000
Newton	5000	*Charlotte	45000
Lowell	1500	*Davidson	3000
Belmont	1500	*Shelby	7000
Mt. Holly	1500	*Salisbury	20000
*Mooresville	6000	*Monroe	6000
*High Point	10000	*Winston-Salem	35000
*Greensboro	30000		

South Carolina

*Rock Hill	14000	Yorkville	5000
Fort Mill	3000	*Chester	12000
Clover	2500	Greer	3500
Fort Lawn	2000		

* These towns had local plants, the others were not electrically lighted until the Southern Power Company's transmission lines were run.

The transmission system of the Southern Power Company is one of the most extensive in the world. At present it is operated almost entirely at 44,000 volts, 60 cycles, three-phase, there being, however, 56 miles of single circuit pole line transmitting current at 11,000 volts. This latter section constitutes a part of the distribution system of the original Catawba plant. Of the 44,000 volt lines, about 240 miles of double circuit and 17 miles of single circuit will, in the near future, carry 100,000 volts.

The Company's staff supplies its own designing engineers and superintendents of construction, although outside engineers are occasionally called into consultation. The entire development work is under the supervision of Mr. W. S. Lee, Second Vice

President and Chief Engineer, who has been active, since the inception of the Company, in the design, development and construction of its hydro-electric plants. To him and to his associate in the pioneer work, Dr. W. Gill Wylie, President of the Company, is largely due the uniform success which has characterized the Company's developments.

A descriptive article covering the transmission and distribution system of the Southern Power Company will appear in the next issue of the Review.

A GRAPHICAL METHOD FOR PREDETERMINING VOLTAGE VARIATION IN D.C. MACHINES

By E. Place

Before an actual trial is made it is sometimes desired to know what change in voltage will result in a direct current generator when one or more elements that control its action is temporarily altered. For instance, how would the terminal voltage be affected if, with no change in the armature or field windings, both the rheostat and speed of rotation were varied a given amount: or suppose that a generator is to be driven by a constant torque applied to the shaft and to run at a certain specified speed; what resistance must be inserted in the external circuit in order that the resulting current shall provide the proper braking effect to give that speed.

Simple as they may appear on the surface, such problems are not easy of accurate solution by ordinary arithmetical processes, and it may be of interest to show how the desired quantities can be readily obtained by graphical methods. In general, the graphical process is not only simpler to perform than the arithmetical, but when applied to problems of the above nature, it has the advantage of showing to the eye more clearly than the other how the action of the machine is affected by certain changes in operating conditions.

In a separately excited direct current generator, the terminal voltage is dependent on the speed of rotation, total current, resistance of armature circuit between machine terminals, effective armature reaction, and field current. The relation of these six variables to one another for any particular machine cannot be expressed by a simple algebraic equation of a form that will give the e.m.f. in terms of the other quantities. But when the total current is zero and the speed is constant, the relation between voltage and field current is definitely shown by what is known as the "saturation" curve of the machine. With the curve drawn to scale and the three other factors known, it is easy to combine these last with values obtained from the curve, and then compute very closely what the action of the machine will be for a variety of conditions.

In a self excited machine, however, the case is somewhat different and much more complicated. The terminal voltage is dependent on the field current, which is itself dependent on the terminal voltage, thus causing a sort of reflex action between the two. This feature of the self-excited machine would seem to give an indeterminate character to its action and thus render it unstable in operation; but, as will appear later, the steady values of both the terminal voltage and field current are fixed by the character of the field winding and the shape of the saturation curve. In what follows, it is assumed that the saturation curve for some particular speed is known from experiment or otherwise, and that the resistance and number of turns per pole of both the shunt and series field windings, as well as the effective armature reaction and the resistance of armature circuit are also known.

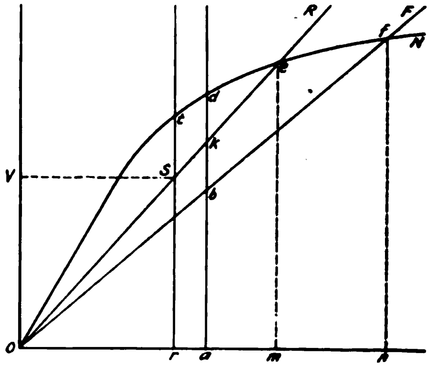


Fig. 1

Shunt Generator

Beginning with the simplest case of a shunt generator, *O N* (Fig. 1) is the saturation curve for the normal speed, vertical distances representing volts induced and horizontal distances ampere turns per pole, in accordance with usual practice. *O R* is a line drawn to represent the total resistance of the shunt circuit, including the rheostat. Its direction from *O* is determined in the following manner: Consider the field coils independent of both the armature and field magnetic circuits, and suppose a current of a known value of *C* amperes to be sent through them all. If *r* is the total resistance of the circuit and *t* the number of turns per pole, *c r* is the volts at ends of the circuit and *c t* the ampere turns produced. Lay off this last value on the horizontal axis, representing it by *O a*. From *a* lay off vertically *a k* equal to *c r* in volts. A line through *o* and *K*, or *O R*, will then be such that for any point on it the ordinate represents impressed volts and absicissa ampere turns. In other words, it shows the ampere turns of shunt excitation corresponding to any given volts impressed on the circuit. Accordingly, it will be designated as the shunt line. If, however, the horizontal axis is laid off to a scale of amperes exciting current instead of ampere turns, then the ratio of ordinate to abscissa for every point on it will be the resistance of the circuit in ohms. In either case the tangent of the angle which this line makes with the horizontal is proportional to the resistance, so that increasing the resistance increases its slope and *vice versa*. In Fig. 1 the line *O F* represents the resistance of the field windings, and therefore for a voltage *K a* impressed on the circuit, *ba* represents the drop on windings, or volts field. *O F* would then be the shunt line for full field.

So far we have considered the field coils without reference to their effect in producing magnetic flux or e.m.f. in the armature.

Now with *O R* for the shunt line as before, let the field coils be separately excited from an independent source of current, so that the impressed volts on the circuit can be varied at pleasure. Starting with zero current in the fields, it will be seen from the figure that as the current increases, the voltage at the terminals of the circuit is less for a given value of ampere turns than the induced volts in the armature. Thus with ampere turns *o a*, the impressed voltage is *a k* while the armature volts is *a d*. Increasing the impressed voltage still further to *e* where the line cuts the saturation curve, it is then equal to the induced volts. Now if the armature and field circuits be thrown together and the independent source of current disconnected, the machine becomes self exciting and the voltage will remain at this value *m e* as long as the speed and rheostat setting remain unchanged; for at no other point on either the shunt line or saturation curve will the voltages at the terminals of both armature and field circuits be the same. This condition of equality of voltage between the armature and field must always exist with a self excited shunt generator, and the point of intersection *e* is thus the steady voltage for no load with the same shunt circuit. It is therefore the point of maximum voltage for this particular rheostat setting. If still operated self exciting and the rheostat be cut out, thus changing the shunt line to *O F*, *f* will then be the maximum volts obtainable with full shunt field. The effect of the small armature current present in producing reaction and voltage drop is here neglected.

The above analysis will also show what the maximum armature volts will be when the machine has a given shunt resistance represented by the line *O R* and is separately excited. If *o v* is the excitation volts, a horizontal line through *v* cuts it at *s* and a vertical through this point intersects the curve at *t*. This line *t r* now becomes the shunt line and *t* gives the maximum no load volts for this excitation. The voltage obtainable at any other speed of armature, with a given change of rheostat resistance, can be determined by tracing a portion of the saturation curve for the new speed and making a construction as indicated above, using the proper shunt line.

The shunt lines of a machine are thus seen to serve a very useful purpose in determining its action for no load condition, and it will now be shown how they may be applied to both shunt and compound generators, whether self or separately excited, working under load.

When an ordinary shunt generator is operating under load with a brush shift the reaction of the armature due to current flowing gives rise to a magnetic effect in opposition to that of the field winding, and is expressed as a certain number of ampere turns. The result is that the effectiveness of the field ampere turns is reduced by this amount, and therefore the magnetic flux and induced volts in the armature are less than the no load values. Besides this, the resistance of the armature circuit consumes a small portion of the induced volts, causing a still further reduction in the terminal voltage. For any given load, then, the terminal voltage must be such that it will satisfy the following condition: The shunt ampere turns due to this excitation diminished by the amount of armature reaction determines a point on the saturation curve which is the induced armature volts. This last diminished by the volts drop in the armature circuit must be the terminal voltage. Both the armature drop and its effective reaction are proportional to the current flowing, and knowing these values it is easy to determine graphically what value of the terminal voltage will meet these conditions. The method of doing this by the use of the shunt lines of the machine, and thus deriving the external characteristic, is shown in Fig. 2. If $o\ v$ is the no load volts, the horizontal line through v cuts the saturation at p and the line $O\ p\ R$ is then the shunt line for self excitation. For full load conditions construct a right triangle $a\ b\ c$, the vertical $a\ b$ being equal to the armature drop in volts and base $b\ c$ equal to the effective armature reaction drawn to the *right* of $a\ b$ as shown. This triangle is then located in the space between the curve and the shunt line, with the vertex touching the curve and the right extremity c of the base touching the shunt line. The height of the base ov_1 gives the terminal volts for this load. For any other load the sides of the triangle would both be lengthened or shortened proportionally, and the new position of the base line located again in the same manner. Thus for half load the sides would be half the length, and so on. In this way, the external characteristic can be worked out for all variations of load as well as of compounding. Starting from no load, it will be seen that for each value of current there are two positions that the triangle can occupy and still satisfy the conditions, giving two values of terminal voltage. For instance, at full load current these values are shown as v_1 and v_2. The maximum value of current for a given shunt line, as $O\ R$, is found from the triangle located at the point t on the curve where the tangent line is parallel to the shunt line. Here the hypothenuse is a maximum, and the current as well as the terminal volts can readily be obtained.

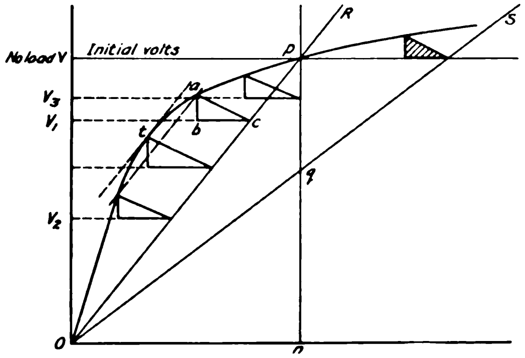


Fig. 2

Since with a shunt machine and a given setting of the rheostat the terminal voltage decreases with increase in load, it is necessary to diminish the rheostat resistance in order to hold up the voltage as the load comes on. The amount of this change in resistance necessary to maintain constant voltage can readily be found. Thus for full load the triangle represented as $a\ b\ c$ must be placed in the position shown by the shaded one in the figure, the base resting on the line $v\ p$ and the vertex on the curve. Through the right extremity the line $O\ S$ is drawn, which is the new shunt line. The decrease in resistance will then be in the ratio of $q\ n$ to $p\ n$. If the machine is separately excited, the external characteristic will be found by the same process, but by using the shunt line $p\ n$. For this case, the terminal voltage for full load, say, would be v_3, a somewhat higher value than is found for self excitation and same no load volts.

In Fig. 3 is shown what would be the effect on the terminal volts of starting with full load and reducing the armature current to zero. If $o\ v$ is the full load volts at terminals, the triangle $a\ b\ c$ for full load will be located as shown and corresponds to the shaded one in the previous figure. $O\ C\ R$ is now the shunt line, and the rise in voltage when the load is thrown off will be on the curve at d where the line cuts it. To maintain the voltage the same at no load, the resistance of the field circuit would be shown by the shunt line $o\ t$ and the increase by the ratio of $s\ t$ to $s\ p$. If the machine is separately excited at volts $o\ v$, the voltage at armature terminals will rise to e when the load is thrown off.

Compound Wound Generator

As was noted above, the decrease of the terminal voltage of a shunt generator as the load increases is due in a large degree to the demagnetizing effect of armature reaction. By the use of a series winding in addition to the shunt winding this reaction can be overcome, or the effect of the series winding increased still further to give a constant terminal voltage as the load increases. By increasing the ampere turns, the series action can be made to boost the voltage so that the rise will be nearly proportional to the load. In such a case, when the armature reaction is not otherwise annulled or compensated for by the use of commutating poles or similar means, the *net* increase of ampere turns of the series winding is the excess of its ampere turns over those of the armature reaction. That is, the shunt ampere turns at any load are increased by an amount equal to the difference between the series ampere turns and ampere turns armature reaction. If the series ampere turns are greater than the reaction, the magnetic flux is increased from no load to full load; if less, the flux is decreased. Since both the armature reaction and the series ampere turns are proportional to the current generated, their difference is also porportional to it. Hence, if a right triangle is constructed similar to that for the shunt machine, but having for base a line the length of which is equivalent to this difference, and drawn to the *left* of the vertical, it can be used to show the action of the compound wound generator at all loads.

In Fig. 4, assume the no load volts to be represented by ov: p is the point on the saturation where the horizontal through v cuts it; $O R$ drawn through p is the shunt line; $a b$ of the triangle $a b c$ is the volts drop of armature for full load current; and $b c$ is the number of series ampere turns *less* the armature reaction. It is located with reference to the curve and shunt line according to the rule for the shunt machine. As shown, the rise in voltage from no load to full load is from v to v_1 without any change in the rheostat. For any other load the length of the sides of the triangle would be increased or decreased accordingly, and the triangle shifted parallel to itself with the points a and c on the curve and line respectively. If the generator is to flat compound at v volts, the base will be reduced to the length $p e$, $d e$ being the armature drop at full load. If the shunt coils are separately excited from a circuit of v volts, the shunt line would then be $p h$, and it is easy to see how the rise of terminal voltage would be increased from no load to full load.

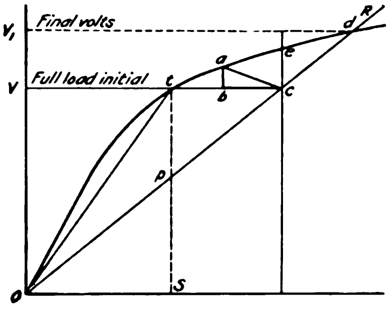


Fig. 3

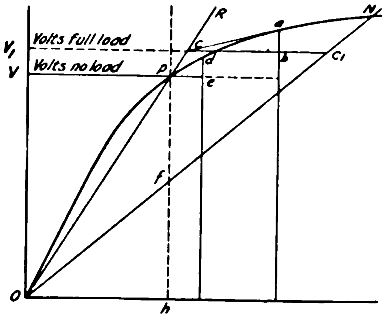


Fig. 4

In the figures the triangle $a b c$ is located to represent its full load position, the point a on the curve showing by its abscissa the total net ampere turns per spool and its ordinate the induced volts in the armature, while the abscissa of the point c is the ampere turns per pole due to the shunt winding alone.

A machine to operate as both shunt and compound generator, say at a range of voltage from no load volts v to full load v_1, would require a shunt winding sufficient to produce ampere turns $v c_1$, the line $O c_1$ being the shunt line in this case and $b c_1$ the effective armature reaction. With the winding so designed, it would require that the rheostat resistance for compound operation be such as to increase the resistance of the short circuit in the ratio of $p h$ to $f h$.

As a further illustration of the use of the graphical method in solving problems relating to the action of generators, we will take the case of a machine driven by a constant torque applied to the shaft and run at a given speed. It is required to find what resistance must be inserted in the external circuit so that the resulting current shall provide the necessary braking effect to maintain this speed.

We will suppose the machine to be a compound wound motor used for mine hoisting, which, when lowering the empty skip, will operate reversed as a generator and allow the skip to descend at a uniform rate. In this case, the shunt fields are to be excited at a constant line voltage and the series field reversed. The normal saturation curve and the coefficient of effective armature reaction, as well as the other constants of the machine, are supposed to be known.

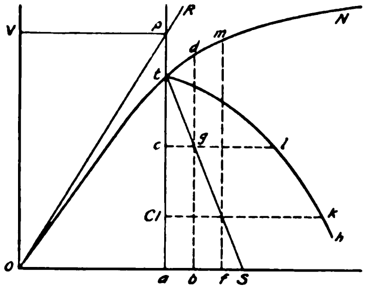


Fig. 5

Let M = moment of applied couple in ft. lbs.
n = speed as generator in r.p.m.
e = induced e.m.f. in the armature
C = current generated.
F = efficiency of transformation; *i.e.*, the ratio of the C^2r in the armature circuit to the power delivered to the shaft.
r = resistance of armature circuit.

The equation between these quantities is:

$$\frac{ec}{n} = \frac{746 \times 2\pi M n F}{33000} \qquad (1)$$

or

$$\frac{e^2}{rn} = K F,$$ which gives the watts developed as heat in the armature and external circuit. Assuming for the present that F is constant for different values of C, and that there is no effective armature reaction, the value of e, and therefore $\frac{e^2}{n}$, can be obtained from the curve so that r will be known and the value of C can be found. This value of C would have to be compared with the value corresponding to the value of F used, as shown by the efficiency curve, and the latter quantity changed if necessary. In this way, by a process of trial and error, the correct value of C can be obtained, and then r.

Assuming, however, that the series winding is such as to overcome the armature reaction and give an excess of ampere turns which increases the induced e.m.f., the watts $e\,c$ can be determined in the manner indicated in Fig. 5. $O\,N$ is the saturation drawn for the speed n, $O\,R$ is the shunt line, and $o\,v$ the excitation voltage on the shunt winding. A vertical through p gives $t\,a$ for the induced voltage at no load, supposing the speed to be kept constant by some means. From t lay off amperes on some convenient scale downward and draw $t\,s$ at such an angle from $t\,a$ that for some current $t\,c$ the distance $c\,g$ shall be the ampere turns series in excess of the armature reaction for current c. For this value of current the induced e.m.f. is $d\,b$ and the watts is $t\,c \times d\,b$. Let $c\,l$ represent these watts. Compute several values in this manner for different assumed current values and plot them in a curve the ordinates of which measured from t are amperes and abscissas are watts as indicated by the line $t\,l\,h$.

From this curve select a value of watts corresponding to that given by equation (1) and note the corresponding current. This will be the required value of current, provided it agrees with that corresponding to the value of F on the efficiency curve of the machine. If it does not agree closely, a new value of F should be chosen and the watts recalculated so that the current from the curve $t\,h$ and the efficiency selected shall check on curve of efficiency. Suppose $t\,c_1$ in the figure is the correct value; $m\,f$ is then the induced e.m.f. and their ratio is the total resistance of the armature circuit, from which the value of the external resistance is readily obtained. If the machine were a plain shunt wound motor, the line $t\,s$ would be drawn on the opposite side of $t\,a$ at the proper angle, but the construction otherwise would be the same as in the present instance.

In the foregoing, it has been assumed that the saturation curve of a machine when generating current is the same as that for no load, and that the coefficient of effective armature reaction is constant for all loads. Strictly speaking, these vary to some extent, but with no change in the brush shift as the load on the machine varies this assumption would not materially affect the result in most cases. The action of direct current motors can be treated in a manner similar to that for generators, and where commutating poles are used to annul armature reaction the details of the graphical solution would necessarily be somewhat modified.

CONSTANT CURRENT REGULATORS

By H. A. Laycock

In the June issue of the General Electric Review, voltage regulators for alternating current work were described. The cycle of operation of the current regulator is practically the same as that of the voltage regulator, with the principal difference that the regulating magnets of the former are designed with current coils instead of voltage coils. The arrangement of these magnets, contacts, levers, etc., vary somewhat, depending upon the work for which the current regulators are to be used.

It will be impracticable to describe all the possible applications and methods of connections of constant current regulators, and therefore only those which have been most frequently called for will be considered.

Fig. 1 shows the connections of a constant current regulator to a dynamic battery, or motor-flywheel set, the motor of which is connected across the line of a railway generator, the current coil of the regulator being in series with the line and the relay connected across the motor field rheostat. The flywheel is either taking from or delivering energy to the line, depending upon the load conditions. It will be noted that should the generator tend to become overloaded, the current in the main control magnet of the regulator will increase, thus closing the contacts of the relay circuit (which are reversed to those of the ordinary voltage regulators), the relay in turn short circuiting the field rheostat of the motor and converting the motor into a generator. This temporary generator feeds out on the line until the current or load is reduced, when the contacts of the regulator open, thus weakening the field of the flywheel motor, and the set immediately becomes a motor driven flywheel. Of course the rheostat in the shunt field of the motor is set at such a point that the regulator is continuously operating; *i.e.*, the contacts are vibrating at the rate of 300 or 400 times a minute, so that the current is maintained practically constant at the normal value for which the regulator has been adjusted. The application of the above regulator is very essential to conditions such as exist on small trolley roads, where the grades encountered require that the generator be overloaded at certain periods, and at others running at only a small per cent. of its normal load. During the latter periods the generator easily drives the flywheel set, which stores up energy enough to carry the car over the peak loads by the reversible action of the motor.

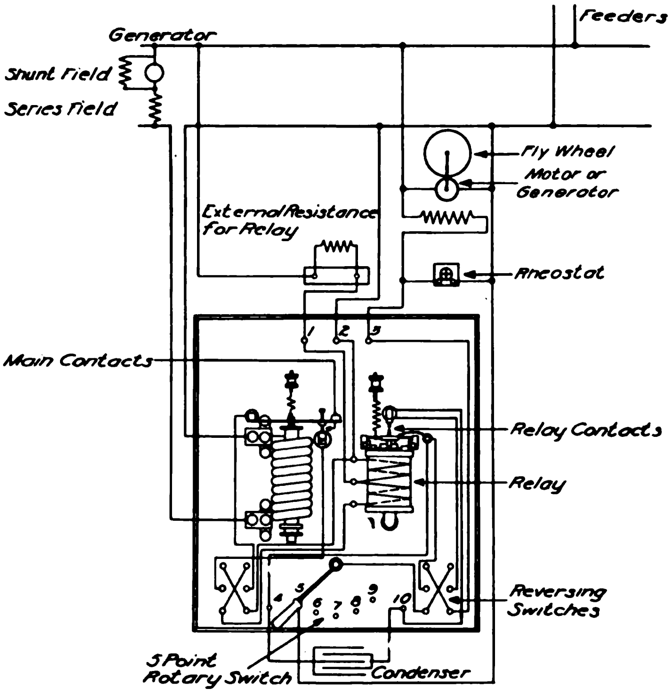


Fig. 1. Connections of Constant Current Regulator for Use with Dynamic Battery, or Motor Flywheel Set

Fig. 2 shows the connections of a constant current regulator for use with storage battery and booster. The current coil of the regulator is connected in the main line, as shown on this diagram, the relay contacts being connected across the booster field rheostat. The difference between the connections of this regulator and the one previously described is that the contacts are arranged in the reverse order, so that should the load increase on the line the main contacts of the regulator will open, thereby opening the relay contacts and lowering the excitation on the shunt field of the booster. As the booster is differentially wound, this will allow the booster to exert its maximum boost due to the series field, and the storage battery will be allowed to feed out on the line. Should the load decrease, the shunt field of the booster will be short circuited and the battery allowed to charge from the line until the reverse action takes place. The operation of the regulator is essentially the same as that of the first regulator described, and takes place practically continuously at a high rate of vibration.

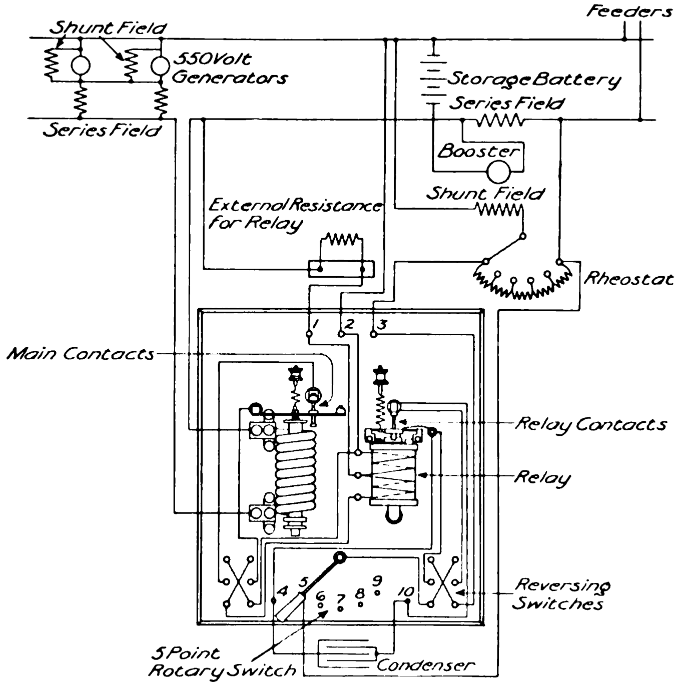


Fig. 2. Connections of Constant Current Regulator to Storage Battery and Booster

Fig. 3 shows the connections of a constant current regulator for use with storage battery and booster, the operation of which is as follows: A shunt is placed in series with the main line to be regulated and supplies current to the main control magnet. In series with this control magnet is a regulating rheostat which is so arranged that the current can be held at the desired value by the adjustment of the dial switch on the rheostat.

The regulator consists of a main control magnet supplied with a core and controlling lever adjusted by a spring. The controlling lever has a double set of contacts, and when actuated in one direction operates one set of relay magnets, and in the other direction the other set of relay magnets. One set of relay contacts is connected across rheostat No. 1 in the field of the shunt wound booster and the second set of relay contacts across another rheostat in the same field. The cycle of operation is as follows: For example, assume that the resistance in series with the main control magnet is adjusted for 1000 amperes on the generator. If the load on the generator increases to 1500 amperes, the current will rise in the main control magnet and cause the upper contacts to close, which operation will in turn cause relay No. 1 to close and short circuit rheostat No. 1. This will produce an unbalancing of the resistance and cause the current to flow around resistance No. 1, through the booster fields, and back to the center tap of the battery, thus building up the voltage on the booster in a direction to lower the voltage impressed on the battery and causing the battery to deliver the proper amount of current to the line; namely, 500 amperes. If the load is suddenly reduced, the main control magnet will be weakened and the lower contacts will close, causing relay No. 2 to close and short circuit rheostat No. 2 on the booster, thus producing an unbalanced effect on the resistance, as before. This will cause the current to flow from the central point of the battery, through the fields of the booster in the opposite direction, thus raising the voltage of the booster and therefore that impressed on the battery, and allowing the latter to charge with a current, the value of which is equal to the difference between the current for which the main control magnet has been previously set and the current demanded by the line.

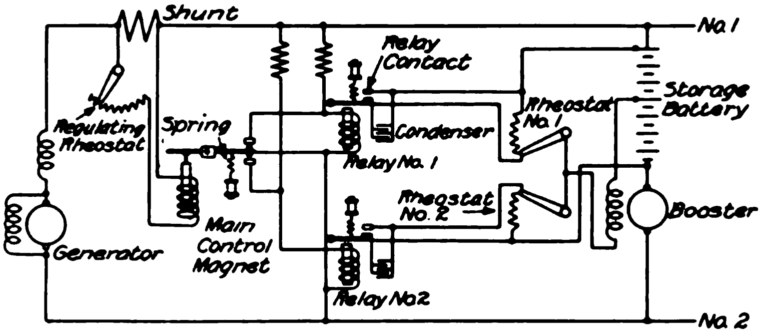

Shunt
No. 1
Relay Contact
Storage Battery
Rheostat No. 1
Regulating Rheostat
Spring
Condenser
Relay No. 1
Rheostat No. 2
Booster
Generator
Main Control Magnet
Relay No2
No. 2

Fig. 3. Another Method of Employing Constant Current Regulator with Storage Battery and Booster

Fig. 4 shows practically the same method of storage battery regulation as that described above, with the exception that the regulator employed in this case is of the floating contact design, due to the fact that an exciter is used to excite the booster field. This type of regulator is only required where the current in the booster field is such that, on account of the high shunt field current, it would be found unpractical to operate the relay contacts directly across the booster field.

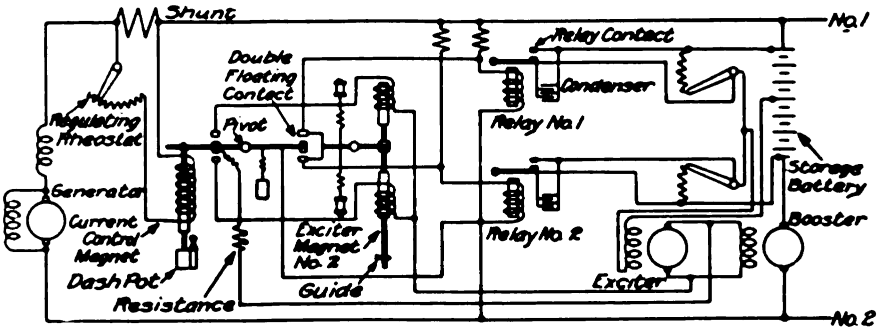

Shunt
No. 1
Relay Contact
Double Floating Contact
Condenser
Pivot
Regulating Rheostat
Relay No. 1
Storage Battery
Generator
Booster
Current Control Magnet
Exciter Magnet No. 2
Relay No. 2
Dash Pot
Resistance
Guide
Exciter
No. 2

Fig. 4. Connections of Constant Current Regulator for Use with Storage Battery and Booster where Field of Latter is Excited by Separate Machine

Constant Current A.C. Regulators

The regulators considered above are intended for use with direct current systems, but as there are numerous applications for regulators for a.c. systems, a few practical applications of these are described below:

Fig. 5 shows the connections of an a.c generator of limited capacity driving a synchronous motor for hoisting purposes, or other piece of apparatus where the motor is subjected to heavy loads thrown on periodically. For example, it will be assumed that the a.c. generator is capable of delivering 100 amperes at 2200 volts, and that the severe loads demanded by the motor will be double the capacity of the generator, while the light loads will only be a very small percentage of this capacity. Another synchronous motor or a.c. generator direct connected to a d.c. motor or generator is installed, the d.c. end of which, when run as a generator, supplies current to a storage battery. The capacity of the synchronous motor generator is the same as that of the original generator, and when run as a motor drives the d.c. machine as a generator and charges the storage battery.

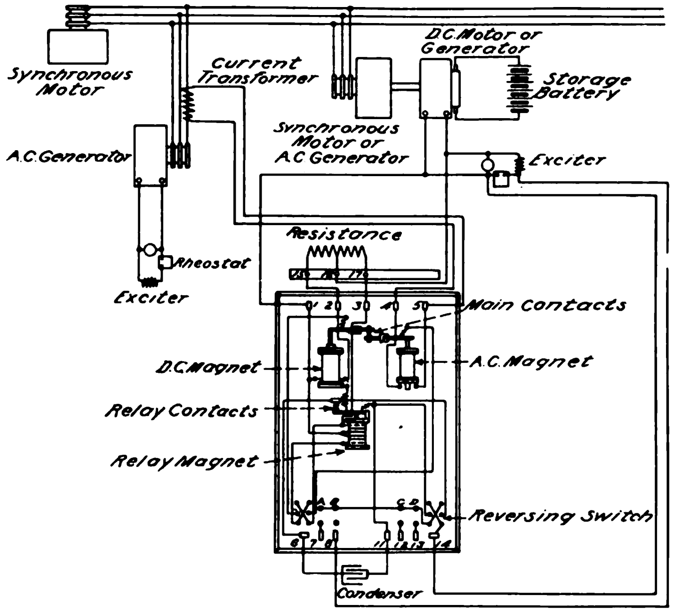

Synchronous Motor
Current Transformer
D.C. Motor or Generator
Storage Battery
Synchronous Motor or A.C. Generator
A.C. Generator
Exciter
Resistance
Rheostat
Exciter
Main Contacts
D.C. Magnet
A.C. Magnet
Relay Contacts
Relay Magnet
Reversing Switch
Condenser

Fig. 5. Connections of Constant Current Regulator to an Alternating Current Generator of Limited Capacity Subject to Heavy Overloads

The cycle of operation with the regulator is as follows: A current transformer of 100 amperes capacity is placed in series with the a.c. generator and connected to the control magnet of the regulator. This control magnet is set to maintain the constant current of 100 amperes. The remaining control magnet of the regulator is connected across the exciter armature which excites the fields of the d.c. motor generator set. The relay contacts of the regulator are connected across the shunt field rheostat of the exciter. Assuming that the hoist motor is running light, the action of the regulator will be to close the contacts across the field rheostat of the exciter, which action will cause the d.c. machine to operate as a generator and charge the battery. If the load on the generator exceeds 100 amperes, due to loading of the hoist motor, the contacts will open, thereby weakening the field of the d.c. generator, which in turn becomes a d.c. motor and takes current from the storage battery. This motor drives the synchronous motor as a generator, which feeds out on the line and assists the a.c. generator in handling the load demanded by the hoist motor.

Fig. 6 shows the elementary connections of a regulator for cutting in and out the end cells of a storage battery, where the maximum voltage of the battery is higher than the voltage used on the lamps or equipment taking current from the battery.

The cycle of operation is as follows: Assume that the battery, fully charged, delivers 140 volts and that the voltage of the lamps is 100. A potential relay is wound for 100 volts and is supplied with two sets of contacts which control a small direct current motor. The motor is connected through a gear to a ratchet switch, the switch being connected to each end cell of the battery. The fineness of regulation of this outfit is limited to the potential of one cell. Assuming that the battery is delivering 140 volts, the upper contacts of the relay will open, thus allowing a sufficient number of cells to be cut out to reduce the voltage of the battery to 100 volts. As the battery discharges and the voltage lowers, the upper contacts will close, thus starting the motor in the opposite direction and cutting in the required number of end cells to restore the voltage to 100. When the battery is charged and delivering 140 volts, the lower contacts of the relay are closed, due to the fact that the pull on the core of the relay is in an upward direction. This regulator is applicable to installations where boosters and generators are not employed.

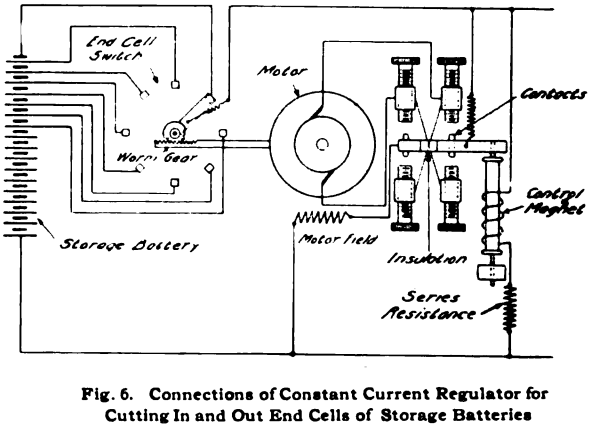

End Cell Switch
Motor
Contacts
Worm Gear
Control Magnet
Storage Battery
Motor field
Insulation
Series Resistance

Fig. 6. Connections of Constant Current Regulator for Cutting In and Out End Cells of Storage Batteries

THE SALE OF MOTORS BY CENTRAL STATIONS*

By S. F. Dibble

Manager Small Motor Department, Chicago Office, General Electric Company

In my opinion the chief reason why a central station should actively exploit the sale of motors is that it can afford to spend time in securing a motor customer, which the dealer, who is dependent on his commission, cannot afford to give. Assume, for instance, the case of a customer who might be induced to purchase and use a motor, the selling price of which is $100.00. The dealer as a rule cannot make more than $15.00 on the transaction, plus, perhaps, a small profit on the installation. Obviously he cannot afford to spend $15.00 worth of time to effect this sale, and the chances are that after he has called once or twice on this customer and found that he is a difficult case he will drop negotiations. Of course, he cannot be blamed, for he has no other source of revenue. If he cannot dispose of his motor at a profit he cannot be expected to make the sale. The central station, however, can very well afford to spend time that is worth much more than the profit on the motor, because it will derive a revenue from the sale of current for that motor for years to come. The dealer may be vigorous and aggressive, but his aggressiveness is circumscribed by the merchandising profit; whereas, with the central station, there is almost no limit to the extent of its activity.

It has been pointed out by one of the best informed power specialists in this country that central station power business is found in three strata.

The first stratum is on the surface and consists of that class of work which, as is apparent to the most casual observer, the electric motor is best fitted to perform. This includes the application of motors to machinery previously driven by hand or by horse-power, where the convenience and economy of the electric drive is evident.

The second stratum lies under the surface and includes business that has to be sought—that which does not come to the central station with a request for a proposition. This includes the application of individual motors to machine tools, etc., in lieu of the wasteful belting and line shafts. To secure this business the customer has to be convinced that he will be benefitted; but he can be convinced by any one reasonably familiar with mechanical and electrical practice.

The third stratum lies away down below the surface and has to be dug out. It is a class of business that looks hopeless to all but the trained power man. This class includes large shops and factories working long hours and driven by steam engines of good efficiency—flour mills, wood-working plants, etc. The central station man realizes that it is in this third stratum that he must look for the business of the future.

The surface was scoured long ago and little remains; the second stratum has been pretty well uncovered and developed; but the third stratum is almost untouched because it requires the hardest kind of work. The business in this stratum is what the central station must have in order to smooth out the load curve and thus increase the profits by increasing the revenue, without a corresponding increase in fixed charges. Fixed charges are the busy bees that work 24 hours per day the year round and the wise central station man is the one who recognizes their ceaseless activities and develops his day load to offset them.

In order to get the business of the second and third strata the central station man must be thoroughly informed on the following subjects: First, his cost of producing current; second, what it costs his prospective customer to produce his power; and third, the amount of power required by the various machines or groups of machines to be operated and the method of applying the power most economically. Large central stations have trained technical engineers and power specialists for this work; the smaller central stations cannot afford them, and in most cases the manager or superintendent is his own power man. He realizes that he needs information and help in order to get this business. How can he get it? Many of those here present know that he can get it by entering into a motor agency agreement with a manufacturer of high grade motors who will keep him supplied at all times with up to date prices, so that he is not handicapped by uncertainty as to whether his prices are right or not. The manufacturer will also supply him with a loose leaf data book that contains a large amount of data, the results of carefully conducted tests, giving the power required to operate nearly all classes of machinery. With this information in his possession the central station man is in a position to talk convincingly to his prospective customer, even though he may not have had previous training along power lines; and as you know, it is useless to talk at all if you cannot talk convincingly.

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*Portion of paper read before the Arkansas Association of Public Utility Operators, Hot Springs, Arkansas.

The form of agreement with which I am most familiar is extremely liberal in its provisions, and there is not a clause in it to which a central station man can justly take exception; for the manufacturers have found that business cannot be secured with a club, and that a liberal policy is the only profitable one. The agreement gives long terms of payment for motors carried in stock or sold on the instalment plan, thereby enabling the central station, without making any investment, to secure a motor customer whom he could not secure if the customer were obliged to pay cash for his motor. The agreement also provides a liberal discount for payment within sixty days from date of shipment as a stimulus for prompt collections and remittances. The agreement does not bind the agency to the exclusive sale of that particular motor, because the manufacturer feels that the advantages of handling that motor is such that the agency will not be disposed to purchase elsewhere except in an emergency. Under this arrangement the central station is in a position to carry motors in stock without making a burdensome investment, and there are decided advantages in doing this:

First. Motors on exhibition in the office or show window, and connected up for operation, have a very decided advertising value. Customers like to see what they are buying and they like to "see the wheels go round."

Second. With motors in stock the central station is in position to make a sale while the proposition is hot, which would frequently be lost if he were compelled to wait for shipment from the factory or warehouse motor customers, as you all know, are subject to severe attacks of cold feet, which are in many cases fatal.

Third. A stock of motors on hand is a constant incentive to the central station man to get busy. He realizes that the bills will fall due before long and he gets out and sells them.

Central station men are busy men. They have a thousand things that need doing, and unless they have a special incentive to hustle along some particular line, they may neglect it; and if it happens to be the sale of motors, then their power business does not grow.

Under the above arrangement the central station is in a position to co-operate with the dealer to mutual advantage, by giving the dealer the privilege of handling the same make of motor and allowing him to purchase it from the central station at cost and under favorable terms. The central station can supply the dealer with price and data books, and in this way thoroughly equip him as a power solicitor and motor salesman. The central station should be advised of all prospective purchasers that the dealer is following; it should assist as much as possible, and should not interfere until it is evident that the business cannot be secured by the dealer. The central station, however, should reserve the right to deal with the customer whenever it seems advisable, and should never be satisfied that a prospect is "dead" until it has carefully examined the corpse; for frequently what appears to be a dead prospect is only a case of suspended animation. I cannot lay too much stress on the importance of the central station following all motor deals in person, regardless of whether the dealer is or is not to make a profit on the sale.

The central station is in a much more favorable position to sell motors than the dealer, for it is apparent to the purchaser that, whereas the dealer is actuated solely by the profit on the sale of the motor, the central station can have no reason for recommending a certain motor except the desire to furnish a machine which will give the most satisfactory service.

Furthermore, the customer likes to deal with one party, and sales are frequently lost because there is a break in the negotiations at the point where the central station secured the contract for power and then left the motor to be sold by someone else. The time to sell the motor is when the power is being sold, and both should be sold by the same individual.

If I have made it clear that it is the duty of the central station to sell motors,—and I realize that most of them appreciate that it is their duty,—then I have only one more point to emphasize. *Sell one make of motor.* Don't shop around. Don't scatter fire. Select one make and stick to it as long as good apparatus and good treatment are received. The central station man and his men will be far more convincing in their arguments if they are thoroughly posted on one make of motor, its talking points and advantages, than they can possibly be by being familiar in a general way with several makes.

Select the best motor you can find. A motor that is not the best is a poor investment for both the station and the user. The premium which you and your customer pay for the best motor is always paid back with compound interest. Select the motor made by the company which is spending dollars where the other manufacturers are spending cents, in improvements in design and construction. You cannot afford to purchase a motor from a company which is satisfied with its product and is standing still.

ALTERNATING CURRENT PORTABLE ELECTRIC (BREAST) DRILL—SINGLE-PHASE

By R. E. Barker

The use of electric power in small units has increased wonderfully within the last few years, and among other comparatively recent applications may be named portable tools.

A persistent demand has been made for a reliable alternating current portable drill; and a most satisfactory direct current drill having been developed, a study of various alternating current drills was made and a small single-phase, 60 cycle portable drill of the repulsion-induction type developed, which possesses all the superior features of the direct current apparatus and has the same general electric characteristics.

It is specially suited to the needs of automobile manufacturers and supply men, contractors, builders, machinists, safe manufacturers, car and stair builders, brass and iron finish workers, etc., etc.

This motor is clearly shown in Fig. 1. It has been strongly designed to withstand the rough usage to which portable devices are frequently subjected; but light weight has also been secured by the judicious use of aluminum alloy castings for end heads, hand hole covers, etc.

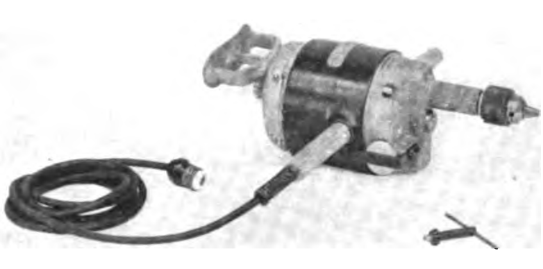


Fig. 1. Alternating Current Portable Drill Fitted with Breast Plate

The motor is provided with a compensated winding and can be furnished for operation upon 110 or 220 volt, 60 cycle circuits. Two side handles are supplied, and an indicating control switch is located within convenient reach of the right hand when grasping the handle. The drill is, therefore, always under the absolute and ready control of the user.

The motor is finished in black japan, with satin finished aluminum end heads, covers, trimmings and breast plate. The side handles are knurled and finished bright. The outfit complete weights only 21 pounds.

Unless otherwise requested, the motor is furnished with breast plate as mentioned above; but an aluminum spade handle may be substituted without extra charge, if it is desired. The spade handle is shown in Fig. 2, and is interchangeable with the breast plate. It may be applied to any type AD, Class 101, Form B alternating current drill with the aid of only a screw driver.

The design of the drill incorporates the features of the smaller drawn shell type motors; the armature having a winding and commutator not unlike those of a direct current machine. Four brushes are used, two being joined by a jumper or short-circuiting lead, while the other two are connected to the compensating section of the field winding. This winding is in general similar to that of an induction motor. The brushes are mounted on a moulded insulating ring and correctly located by a set screw in the commutator end cap. It is important that no change in the setting or angular position of the brush-holder be made, as it is adjusted and set for the best operating position at the factory.

Access to the brush-holders is secured by the removal of the hand hole covers, as shown in Fig. 3. This construction permits quick and easy examination of the brushes and commutator, at the same time affording ample protection to the current carrying parts. All electrical parts are well insulated and protected so that there is no liability of the user receiving a shock.

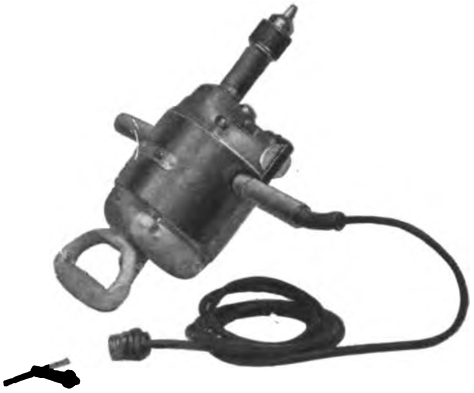


Fig. 2. Alternating Current Portable Drill Fitted with Spade Handle

A Jacobs chuck, which will take drills up to and including ⅜″ in diameter, and the necessary tightening key are included in the outfit.

The drill can take current from any standard screw base receptacle or lamp socket, and the flexible cord and Edison attaching plug which are furnished permit of operating the drill at a radius of ten feet from the source of current supply. Of course, a longer cord, to extend this radius, may be attached by the user if desired.

The amount of power required depends upon the character of the work, the material worked, the condition of the drill point (sharp or dull), the manner in which the drill is handled, etc. However, the approximate operating data at 60 cycles, 110 volts, when drilling holes one inch deep, is roughly as follows:

Size of Drill	IN CAST IRON			IN MACHINE STEEL		
	Amps.	Watts	Time	Amps.	Watts	Time
⅛	1.3	110	22 sec.	1.3	110	30 sec.
¼	1.7	150	17 sec.	1.7	150	28 sec.
⅜	2.1	185	27 sec.	2.15	200	95 sec.

Free reading, 1.15 amps., 88 watts; speed 1125 r.p.m. at drill spindle.

The efficiency of this drill is about 50 per cent. throughout the greater part of its working range. It has sufficient power to operate a ⅜ in. drill in machine steel, cast iron and brass. It will also operate satisfactorily a ¾ in. wood bit.

The curves of Fig. 4 are approximately correct for the 60 cycle, 110 volt motor, and are given for general information.

Fig. 5 shows a comparison of speed and torque of the alternating current (Type AD Class 101) and direct current (Type DD Class 101) drills, and indicates that the operating speeds of the two types are alike within a few per cent. Hence, equally good service may be obtained from either type of machine.

Attention is called to the fact that, in order to have the drill operate most satisfactorily, it should be carefully used; cramping of the drill point in the hole should be avoided, as well as such strong pressure in feeding as to stall the motor. No drills are furnished with the outfit.

The motor is not provided with the usual type of self-oiling device, as the tool is used in all conceivable positions, and if such a device were employed there would be great annoyance from the unavoidable leakage of oil. In its stead, small chambers are provided which will hold a small quantity of oil and which should be frequently filled. With this arrangement no trouble will be experienced from leakage.

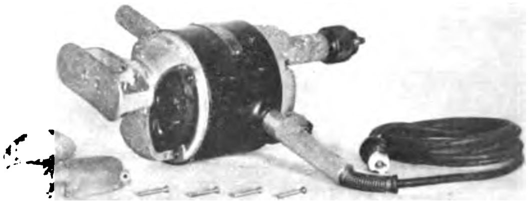


Fig. 3. Alternating Current Portable Drill with Covers Removed for Access to Commutators

Briefly enumerated the salient features of the motor are as follows:

The drill is portable, compact, durable, light in weight, and safe and reliable in operation.

It is easy to handle and economical in service.

It saves time, results in work being more rapidly accomplished, and affords an actual saving in money.

It has been called an "incentive to the workman, a satisfaction to the foreman, and a money maker for the contractor."

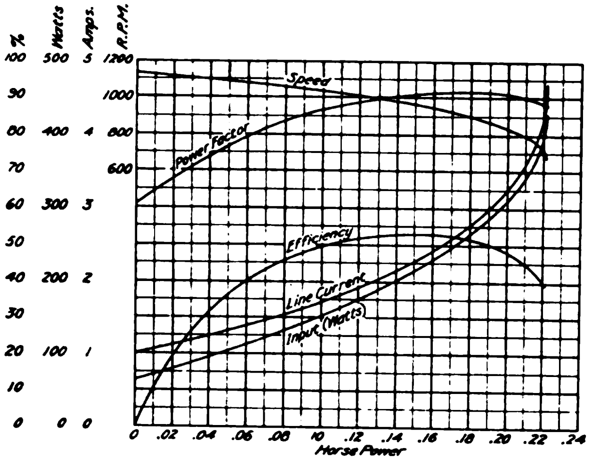


Fig. 4. Load Efficiency Test of Alternating Current Drill at 60 Cycle

Two letters of endorsement from practical manufacturers may be quoted:

"We found upon trial that where a great many holes were to be drilled at one time, we could use the machine to advantage. The speed was apparently suited to our work and the power was more than ample. The motor reached full speed almost instantly upon applying the current, which is desirable under certain conditions.

"We also noticed that there was very little noise from the motor itself, or from the gears. We consider the long neck, upon which the chuck is attached, a good feature, as it serves as a handle to guide the drill."

"Regarding the performance of the small electric breast drills which we have had of your manufacture, we are pleased to advise you that these drills are giving us good service. Better than anything we have had in use of this class of tools."

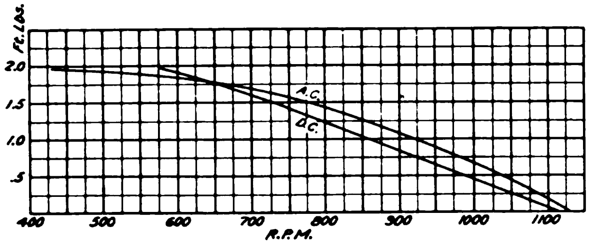


Fig. 5. Speed-Torque Curve A.C. Drill Compared with that of D.C. Drill

This new drill has been fully tried out, and is now being manufactured in quantities, so that prompt shipments can be made from stock.

THE ARMY SIGNAL SCHOOL

By Captain A. C. Knowles

Signal Corps, Instructor Army Signal School

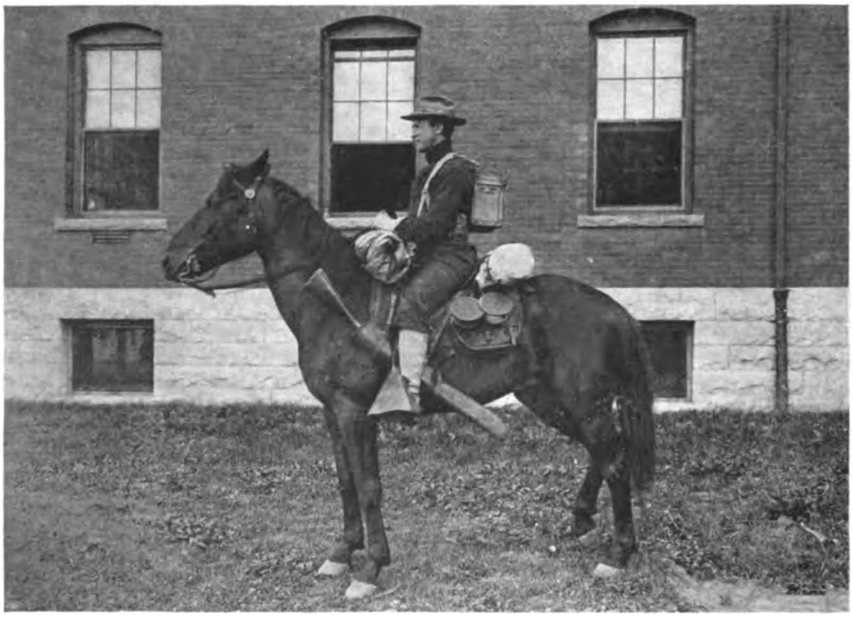
Six years ago the Army Signal School had no existence. It may truly be said that to the great majority of our army officers, particularly in the infantry and cavalry, the signal corps itself was a vague, if not unknown, quantity. But few of us ever came in contact with its personnel; the scope of its work in time of peace, in domestic disturbances, in times of disaster or in time of war, seldom if ever was presented to the public (and I refer here particularly to the army public) in a way which stamped it upon their minds as an invaluable auxiliary in a modern army.

Until recent years there seems always to have existed in our own, as well as other armies, an unjust contempt for any soldier who did not actually fight with his own hands. The spectacular is still a prominent relic of barbarism, which sways our imagination and influences our better judgment. The awe-inspiring picture of our war hero dashing madly along the front of his troops, urging them on to victory, is still a vivid recollection. In the recent Russo-Japanese war the now world-renowned general did no such thing. We see him sitting quietly in his tent twelve miles behind the firing line, away from the immediate scene of some local action, away from the noise and confusion of battle, where, free from conditions which might urge him to command only a part, he controls the whole.

How infinitely necessary in all future wars of any magnitude will be that auxiliary arm which renders this control of a modern army possible. It is believed that the day is not far distant when another distinct combatant arm will be added to our service.

The modern battle-field has been frequently compared to a chess-board. On the one hand we have presented a picture of a fixed number of pieces, each occupying its proper position, each moving in accordance with prescribed rules, and the strength of each a positive factor. The disposition, the probable intentions of the opposing forces; in brief, the general and special situations on each side are at all times accurately known to the master minds, who, besides, have their respective forces constantly under their absolute control. On the other hand, how confusing the game waged on the battle-field! After the first few moves, doubt and ignorance usually prevail; units moving independently, retreating when they should advance, advancing when they should stand fast, complicate and hamper the most carefully laid plans at every turn. The master mind no longer has absolute control of his pieces, he knows but little of his enemy, and the game resolves itself into blind man's buff. No matter how wisely the plan of action is prepared, the chances are few indeed against an enemy of equal strength, pluck, equipment, etc., actuated by a mind in touch with all the parts.

What a contrast between these two pictures! The first shows us a perfect system of information, with perfect means of conveying it and perfect control of the movements of the men. The second portrays these lacking or very imperfect.



Signal Corps man equipped for field with 1 mile buzzer wire strapped to saddle and field buzzer carried as knapsack

The importance of perfecting these instruments of battle cannot be exaggerated; and ranking as an instrument of the greatest importance in the "service of transmission," is the Signal Corps.

The Signal Corps is standing at the threshold of a new era, an era which is full of possibilities and usefulness. It has become a corps highly technical in character, and as its future depends upon those instructed with the work, its commissioned personnel should be systematically trained in this work. The Signal School is a means to this end, its existence being due to the efforts of those who look far into the future.

The Signal Corps especially needs creative and constructive students of the practical sort, who, while being able to retain a thoroughly discipled attitude at all times toward the opinions of superiors, will nevertheless push forward into new lines of development, which alone can insure keeping progress with the armies of other nations. The two objects kept in view in forming the curriculum of the Army Signal School have been the following: (1) To prepare each student officer for the active and technical duties required in case of immediate declaration of war: (2) to investigate and co-ordinate the whole subject of lines of information by thoroughly practical methods, with a view of realizing better and more efficient tactical and strategical methods of operating armies in the campaign.

The value of the course to an officer who may be fortunate enough to secure the detail is, to me, pronounced in character, even though he never willingly elects to become a member of, or temporarily attached to, the corps. I wish to forestall the possible charge of rhapsodizing, and if I appear to be over-enthusiastic in comment, it should be borne in mind that my comparison is in the nature of "before and after."

The creative and constructive student referred to above is here afforded every opportunity and encouragement in the matter of original thought and research. The school is now equipped with the finest laboratory in the service. A company of trained signal corps men is at its command whenever its services are required in the experiments and problems in the field. The student is offered a strong stimulus to form his own opinions on military subjects, and a respect for the opinions of others.

COURSE OF STUDY

The course of study is embraced in four departments, as follows:

Field wireless pack set in operation; showing also hand generator

I—The Department of Field Signaling
II—The Department of Signal Engineering
III—The Department of Topography
IV—The Department of Languages

I. Field Signaling

The study of this subject is divided into two parts, theoretical and practical, and comprises optical, acoustical, and electrical signaling.

It is conducted by means of lectures, recitations from the authorized manuals, technical conferences, problems, and practical instruction in the use of the various instruments and appliances required for military signaling in all its branches.

The course comprises the following subjects or fields of inquiry:

(a) Electrical equipment for military lines of information
  The Buzzer
  Field Telephone
  Field Induction Telegraphy
  Field Wireless Telegraphy
  Combat Transportation
  Types of Wire Used for Field Service

(b) Visual Signaling
  Field Visual Signaling Apparatus
  The Heliograph
  The Acetylene Field Lantern
  Rockets and Bombs
  Codes and Ciphers
  Field Glasses and Telescopes

(c) Balloons and Flying Machines

(d) Logistics as applied to Signal Troops

II. Signal Engineering

The study of this subject is also divided into two parts, theoretical and practical, including instruction in laboratory work.

The theoretical instruction in signal engineering is conducted by means of lectures, recitations, technical conferences, and problems, and comprises the study of the fundamental laws of electrical engineering so far as may be necessary for a thorough understanding of all electrical apparatus, devices, or instruments used by the Signal Corps in the field, in fire-control work for coast artillery, in the installation, operation, and maintenance of telegraph lines and submarine cables, in the construction and operation of wireless telegraph stations, in the installation and operation of steam, gas, and oil engines, and in military aeronautics and photography. The laboratory course embraces practical instruction in making fundamental electrical measurements, and in the operation, repair, and maintenance of the various instruments and appliances used by the Signal Corps.

III. Topography

The student officers of the Army Signal School, who are graduates of the Army School of the Line, are given a course of instruction in sketching similar to that given student officers of the Army Staff College. The student officers, not graduates of the Army School of the Line, are given a theoretical and practical course of instruction in topography similar to that given in the Army School of the Line, to include map reading and sketching.

Opening Station by means of Cavalry Buzzer

IV. Languages

The course in languages is elective, and comprises instruction in French or German, as preferred by the student officer: Provided, that no student officer is permitted to elect either of these languages unless he has a good conversational knowledge of Spanish. A student officer who has not a good conversational knowledge of Spanish takes a course in that language. The course in each language will comprise instruction in reading, writing, and speaking, the special object being the acquirement of a conversational knowledge of the language.

Thesis

Each student officer prepares a thesis on some professional subject approved by the academic board.

Technical Conferences

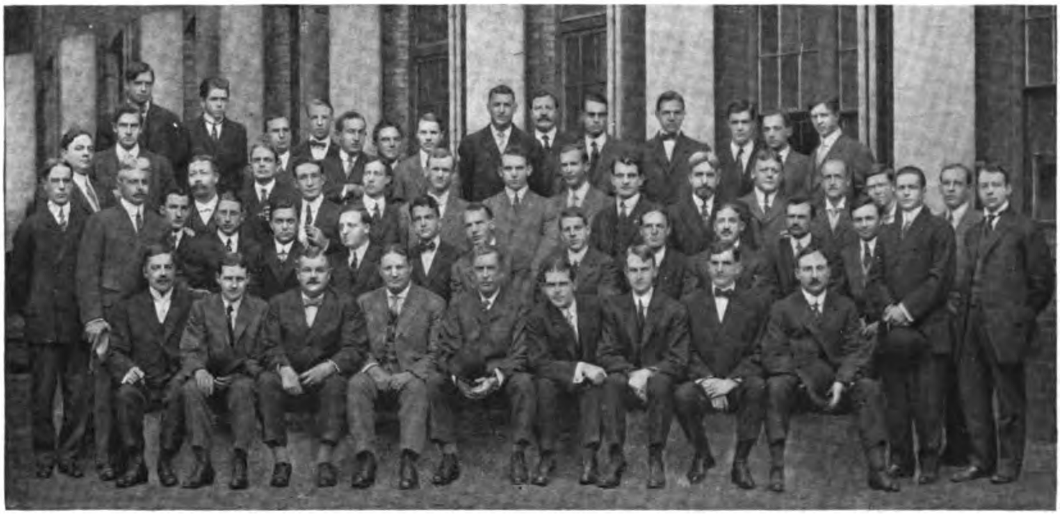
There is conducted in connection with the Army Signal School, under the general supervision of the assistant commandant, a series of technical conferences for the report, criticism, and discussion of papers pertaining to military field signaling or signal engineering procured from current military journals or other available sources.

These meetings are held ordinarily semimonthly, and are conducted by the cooperation of the senior instructors, instructors, and student officers, who are required to present verbal reports, abstracts, or written *precis* of articles of importance for general discussion and criticism at its meetings.

All graduates of the Army Signal School and all officers of the Signal Corps may be solicited to contribute to the success of these conferences by correspondence or otherwise.

MEETING OF SMALL MOTOR SPECIALISTS

The photograph reproduced below shows the group of General Electric men who were in attendance at the meeting of Small-Motor Specialists held at the Lynn Works of the Company on October 26th, 27th and 28th.



From left to right the men composing the group are as follows:

First Row

E. J. McDuffee (standing)
C. H. Scott (standing)
E. L. Cooley
A. H. Meyrose
W. S. Brayton
M. N. Torrence
F. M. Kimball
S. F. Dibble
C. A. Raymond
W. C. Coles
J. S. Baker
H. A. Crammond (standing)
R. E. Barker (standing)

Second Row

F. S. Hartman (standing)
W. H. Coggswell
C. R. Beardsley
C. D. Crowell
W. S. Kennedy
W. S. Leggett
J. F. Carrick
J. E. Mellett
R. W. Kingsbury
C. W. Howgate
W. L. Merrill
G. A. Maier
L. E. Trotter (standing)

Third Row

E. L. Farrar (standing)
A. C. Parsons
B. B. Haralson
C. L. Martin
E. W. Gowin
C. H. Howell
L. G. Gresham
J. M. Poyner
C. A. Kelsey
J. M. Knox
C. D. Knight
J. W. Ham
H. M. MacMasters

Fourth Row

A. A. Anderson
H. T. Canfield
F. R. Davis
E. V. Wetmore
L. E. Smith
J. T. Queeny
C. W. Bartlett
E. P. Coles
M. J. Fitch
L. E. Underwood
J. F. Johnson
H. D. Hutchison
W. A. Watkins
H. V. Rudolph

These meetings bring together expert motor engineers from all over the country; they are held for the purpose of discussing the recent developments that have taken place in this particular field of electrical activity. New types of machines and improvements in apparatus are described and the apparatus itself examined. Papers bearing upon the various technical and commercial phases of the industry are read and discussed. By these meetings, each man is kept intimately in touch with the advances that have been made by the factory; and by the interchange of information between the different specialists, the experience of each becomes available to all. Upon returning to his own field, each man carries with him the information which has been accumulated by the entire group, and is thoroughly posted regarding the latest improvements in machinery and engineering practice, etc. This information accrues directly to the benefit of the customer, be he a central station manager who desires to increase his load, a mill owner with some problem of drive to solve, or a consulting engineer with an isolated plant to install.

The article by Mr. S. F. Dibble, on the sale of motors by central stations; and that by Mr. R. E. Barker, on alternating current portable electric drills, contained in the present number of the REVIEW, were among the subjects presented at this meeting. Other papers that are of general interest will appear in later issues.

TRANSMISSION LINE CONSTANTS

PART VI

TABLE XXIII

STRANDED CABLES

f = 25 Cycles

INDUCTIVE REACTANCE

THREE-PHASE

Loop Formed by Two Wires of a Three-Phase Transmission Line

Reactance of loop = $\sqrt{3}$ reactance for single line

Ohms per 1000 Feet

Interaxial Distance, Inches	SIZE OF WIRE													
	500,000	450,000	400,000	350,000	300,000	250,000	0000	000	00	0	1	2	3	4
1	.0206	.0215	.0225	.0235	.0248	.0263	.0277	.0296	.0315	.0334	.0353	.0374	.0393	.0412
2	.0320	.0329	.0339	.0349	.0362	.0377	.0391	.0410	.0429	.0448	.0467	.0488	.0507	.0526
3	.0388	.0397	.0407	.0417	.0430	.0445	.0459	.0478	.0497	.0516	.0535	.0556	.0575	.0594
4	.0435	.0444	.0454	.0464	.0477	.0492	.0506	.0525	.0544	.0563	.0582	.0603	.0622	.0641
5	.0473	.0482	.0492	.0502	.0515	.0530	.0544	.0563	.0582	.0601	.0620	.0641	.0660	.0679
6	.0502	.0511	.0521	.0531	.0544	.0559	.0573	.0592	.0611	.0630	.0649	.0670	.0689	.0708
9	.0570	.0579	.0589	.0599	.0612	.0627	.0641	.0660	.0679	.0698	.0717	.0738	.0757	.0776
12	.0618	.0627	.0637	.0647	.0660	.0675	.0689	.0708	.0727	.0746	.0765	.0786	.0805	.0824
18	.0684	.0693	.0703	.0713	.0726	.0741	.0755	.0774	.0793	.0812	.0831	.0852	.0871	.0890
24	.0732	.0741	.0751	.0761	.0774	.0789	.0803	.0822	.0841	.0860	.0879	.0900	.0919	.0938
30	.0769	.0778	.0788	.0798	.0811	.0826	.0840	.0859	.0878	.0897	.0916	.0937	.0956	.0975
36	.0798	.0807	.0817	.0827	.0840	.0855	.0869	.0888	.0907	.0926	.0945	.0966	.0985	.1004
42	.0824	.0833	.0843	.0853	.0866	.0881	.0895	.0914	.0933	.0952	.0971	.0992	.1011	.1030
48	.0847	.0856	.0866	.0876	.0889	.0904	.0918	.0937	.0956	.0975	.0994	.1015	.1034	.1053
54	.0866	.0875	.0885	.0895	.0908	.0923	.0937	.0956	.0975	.0994	.1013	.1034	.1053	.1072
60	.0883	.0892	.0902	.0912	.0925	.0940	.0954	.0973	.0992	.1011	.1030	.1051	.1070	.1089
72	.0914	.0923	.0933	.0943	.0956	.0971	.0985	.1004	.1023	.1042	.1061	.1082	.1101	.1120
84	.0940	.0949	.0959	.0969	.0982	.0997	.1011	.1030	.1049	.1068	.1087	.1108	.1127	.1146
96	.0961	.0970	.0980	.0990	.1003	.1018	.1032	.1051	.1070	.1089	.1108	.1129	.1148	.1167
108	.0980	.0989	.0999	.1009	.1022	.1037	.1051	.1070	.1089	.1108	.1127	.1148	.1167	.1186
120	.0997	.1006	.1016	.1026	.1039	.1054	.1068	.1087	.1106	.1125	.1144	.1165	.1184	.1203
132	.1013	.1022	.1032	.1042	.1055	.1070	.1084	.1103	.1122	.1141	.1160	.1181	.1200	.1219
144	.1028	.1037	.1047	.1057	.1070	.1085	.1099	.1118	.1137	.1156	.1175	.1196	.1215	.1234
156	.1040	.1049	.1059	.1069	.1082	.1097	.1111	.1130	.1149	.1168	.1187	.1208	.1227	.1246
168	.1053	.1062	.1072	.1082	.1095	.1110	.1124	.1143	.1162	.1181	.1200	.1221	.1240	.1259
180	.1065	.1074	.1084	.1094	.1107	.1122	.1136	.1155	.1174	.1193	.1212	.1233	.1252	.1271

INDUCTIVE REACTANCE

THREE-PHASE

Loop Formed by Two Wires of a Three-Phase Transmission Line

TABLE XXIV

STRANDED CABLES

f = 60 Cycles

Reactance of loop = $\sqrt{3}$ reactance for a single line

Ohms per 1000 Feet

Interaxial Distance, Inches	SIZE OF WIRE													
	500,000	450,000	400,000	350,000	300,000	250,000	0000	000	00	0	1	2	3	4
1	.0495	.0514	.0538	.0564	.0596	.0632	.0665	.0712	.0757	.0803	.0830	0899	.0944	.0990
2	.0771	.0790	.0814	.0840	.0872	.0908	.0941	.0988	.1033	.1079	.1126	.1175	.1220	.1266
3	.0932	.0951	.0975	.1001	.1033	.1069	.1102	.1149	.1194	.1240	.1287	.1336	.1381	.1427
4	.1046	.1065	.1089	.1115	.1147	.1183	.1216	.1263	.1308	.1354	.1401	.1450	.1495	.1541
5	.1134	.1153	.1177	.1203	.1235	.1271	.1304	.1351	.1396	.1442	.1489	.1538	.1583	.1629
6	.1205	.1224	.1248	.1274	.1306	.1342	.1375	.1422	.1467	.1513	.1560	.1609	.1654	.1700
9	.1368	.1387	.1411	.1437	.1469	.1505	.1538	1585	.1630	.1676	.1723	.1772	.1817	.1863
12	.1430	.1499	.1523	.1549	.1581	.1617	.1650	.1697	.1742	.1788	.1835	.1884	.1929	.1975
18	.1642	.1661	.1685	.1711	.1743	.1779	.1812	.1859	.1904	.1950	.1997	.2046	.2091	.2137
24	.1756	.1775	.1799	.1825	.1857	.1893	.1926	.1973	.2018	.2064	.2111	.2160	.2205	.2251
30	.1844	.1863	.1887	.1913	.1945	.1981	.2014	.2061	.2106	.2152	.2199	.2248	.2293	.2339
36	.1916	.1935	.1959	.1985	.2017	.2053	.2086	.2133	.2178	.2224	.2271	.2320	.2365	.2411
42	.1980	.1999	.2023	.2049	.2081	.2117	.2150	.2197	.2242	.2288	.2335	.2384	.2429	.2475
48	.2032	.2051	.2075	.2101	.2133	.2169	.2202	.2249	.2294	.2340	.2387	.2436	.2481	.2527
54	.2078	.2097	.2121	.2147	.2179	.2215	.2248	.2295	.2340	.2386	.2433	.2482	.2527	.2573
60	.2122	.2141	.2165	.2191	.2223	.2259	.2292	.2339	.2384	.2430	.2477	.2526	.2571	.2617
72	.2194	.2213	.2237	.2263	.2295	.2331	.2364	.2411	.2456	.2502	.2549	.2598	.2643	.2689
84	.2254	.2273	.2297	.2323	.2355	.2391	.2424	.2471	.2516	.2562	.2609	.2658	.2703	.2749
96	.2307	.2326	.2350	.2376	.2408	.2444	.2477	.2524	.2569	.2615	.2662	.2711	.2756	.2802
108	.2355	.2374	.2398	.2424	.2456	.2492	.2525	.2572	.2617	.2663	.2710	.2759	.2804	.2850
120	.2395	.2414	.2438	.2464	.2496	.2532	.2565	.2612	.2657	.2703	.2750	.2799	.2844	.2890
132	.2433	.2452	.2476	.2502	.2534	.2570	.2603	.2650	.2695	.2741	.2788	.2837	.2882	.2928
144	.2467	.2486	.2510	.2536	.2568	.2604	.2637	.2884	.2729	.2775	.2822	.2871	.2916	.2962
156	.2500	.2519	.2543	.2569	.2601	.2637	.2670	.2717	.2762	.2808	.2855	.2904	.2949	.2995
168	.2528	.2547	.2571	.2597	.2629	.2665	.2698	.2745	.2790	.2836	.2883	.2932	.2977	.3023
180	.2555	.2574	.2598	.2624	.2656	.2692	.2725	.2772	.2817	.2863	.2910	.2959	.3004	.3050

TABLE XXV

STRANDED CABLES

f = 100 Cycles

INDUCTIVE REACTANCE

THREE-PHASE

Reactance of loop = $\sqrt{3}$ reactance for single line

Ohms per 1000 Feet

Loop Formed by Two Wires of a Three-Phase Transmission Line

Interaxial Distance, Inches	SIZE OF WIRE													
	500,000	450,000	400,000	350,000	300,000	250,000	0000	000	00	0	1	2	3	4
1	.0825	.0858	.0898	.0941	.0992	.1053	.1107	.1185	.1261	.1337	.1416	.1496	.1572	.1648
2	.1283	.1316	.1356	.1399	.1450	.1511	.1565	.1643	.1719	.1795	.1874	.1954	.2030	.2106
3	.1550	.1583	.1623	.1666	.1717	.1778	.1832	.1910	.1986	.2062	.2141	.2221	.2297	.2373
4	.1742	.1775	.1815	.1858	.1909	.1970	.2024	.2102	.2178	.2254	.2333	.2413	.2489	.2565
5	.1891	.1924	.1964	.2007	.2058	.2119	.2173	.2251	.2327	.2403	.2482	.2562	.2638	.2714
6	.2009	.2042	.2082	.2125	.2176	.2237	.2291	.2369	.2445	.2521	.2600	.2680	.2756	.2832
9	.2278	.2311	.2351	.2394	.2445	.2506	.2560	.2638	.2714	.2790	.2869	.2949	.3025	.3101
12	.2467	.2500	.2540	.2583	.2634	.2695	.2749	.2827	.2903	.2979	.3058	.3138	.3214	.3290
18	.2736	.2769	.2809	.2852	.2903	.2964	.3018	.3096	.3172	.3248	.3327	.3407	.3483	.3559
24	.2926	.2959	.2999	.3042	.3093	.3154	.3208	.3286	.3362	.3433	.3517	.3597	.3673	.3749
30	.3075	.3108	.3148	.3191	.3242	.3303	.3357	.3435	.3511	.3587	.3666	.3746	.3822	.3898
36	.3194	.3227	.3267	.3310	.3361	.3422	.3476	.3554	.3680	.3706	.3785	.3865	.3941	.4017
42	.3300	.3333	.3373	.3416	.3467	.3528	.3582	.3660	.3736	.3812	.3891	.3971	.4047	.4123
48	.3388	.3421	.3461	.3504	.3555	.3616	.3670	.3748	.3824	.3900	.3979	.4059	.4135	.4211
54	.3465	.3498	.3538	.3581	.3632	.3693	.3747	.3825	.3901	.3977	.4056	.4136	.4212	.4288
60	.3534	.3567	.3607	.3650	.3701	.3762	.3816	.3894	.3970	.4046	.4125	.4205	.4281	.4357
72	.3655	.3688	.3728	.3771	.3822	.3883	.3937	.4015	.4091	.4167	.4246	.4326	.4402	.4478
84	.3757	.3790	.3830	.3873	.3924	.3985	.4039	.4117	.4193	.4269	.4348	.4428	.4504	.4580
96	.3845	.3878	.3918	.3961	.4012	.4073	.4127	.4203	.4281	.4357	.4436	.4516	.4592	.4668
108	.3923	.3956	.3996	.4039	.4090	.4151	.4205	.4283	.4359	.4435	.4514	.4594	.4670	.4746
120	.3995	.4028	.4068	.4111	.4162	.4223	.4277	.4355	.4431	.4507	.4586	.4666	.4742	.4818
132	.4055	.4088	.4128	.4171	.4222	.4283	.4337	.4415	.4491	.4567	.4646	.4726	.4802	.4878
144	.4113	.4146	.4186	.4229	.4280	.4341	.4395	.4473	.4549	.4625	.4704	.4784	.4860	.4936
156	.4168	.4201	.4241	.4284	.4335	.4396	.4450	.4528	.4604	.4680	.4759	.4839	.4915	.4991
168	.4215	.4248	.4288	.4331	.4382	.4443	.4497	.4575	.4651	.4727	.4806	.4886	.4962	.5038
180	.4261	.4294	.4334	.4377	.4428	.4489	.4543	.4621	.4697	.4773	.4852	.4932	.5008	.5084

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JANUARY, 1909

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1909

Loading Large Transformer for Road Transportation in India
"Foreign Transportation Problems"—Page 21

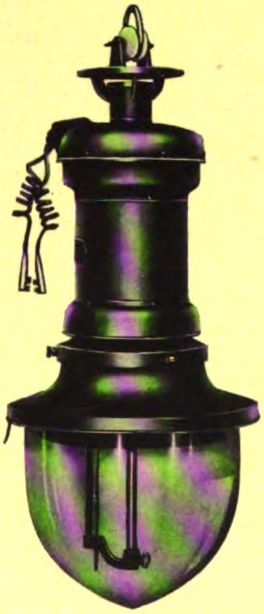
VGA

Series Luminous Arc Lamps

For 4-Ampere Direct Current Circuits

Exhaustive experimental and service tests warrant the statement that from every viewpoint series luminous arc lamps are ideal for street lighting.

Some Reasons Why



Power consumption is 60% less and effective illumination 30% more than with the 480-watt carbon arc lamps.

Only electrode that must be renewed regularly has a life of 175 to 200 hours thus reducing the cost of trimming.

Enclosing globes are not required thus eliminating this item of maintenance.

The light is distributed and diffused to better advantage because of the permanent position and character of the luminous arc. The long steady arc eliminates heavy shadows and at the same time produces the maximum distribution along the horizontal axis.

That these points of superiority are appreciated is evidenced by the fact that over 25,000 luminous arc lamps are used by the largest lighting companies of the country

1979

Motor Drive for Railway Repair Shops

LATHES DRIVEN BY GENERAL ELECTRIC MOTORS

There is no belt driven machine tool in the railway repair shop that can not be run more satisfactorily and more profitably by individual motor drive

The absence of belts and long lines of shafting gives more head room, making the handling of heavy parts easier and allowing much better shop lighting

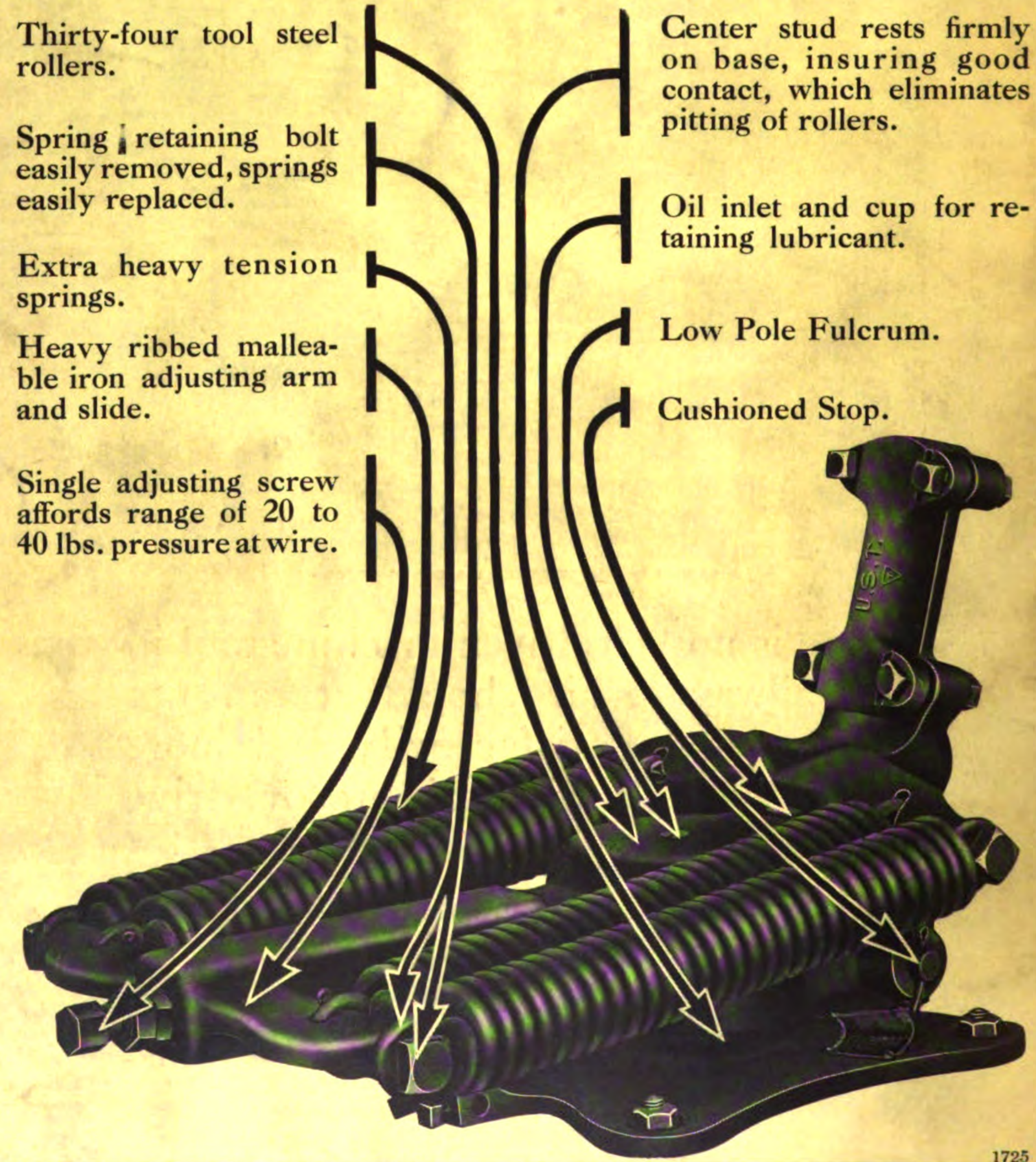
The experience of the most modern machine and repair shops has clearly demonstrated the desirability of direct electric drive for each machine

1980

US-13 Trolley Base

Latest Type — Roller Bearing — Total Overall Height, 5 Inches

Specially adapted for high-speed interurban service. The sensitiveness of this base *insures minimum wear of trolley wheel*



Thirty-four tool steel rollers.

Spring retaining bolt easily removed, springs easily replaced.

Extra heavy tension springs.

Heavy ribbed malleable iron adjusting arm and slide.

Single adjusting screw affords range of 20 to 40 lbs. pressure at wire.

Center stud rests firmly on base, insuring good contact, which eliminates pitting of rollers.

Oil inlet and cup for retaining lubricant.

Low Pole Fulcrum.

Cushioned Stop.

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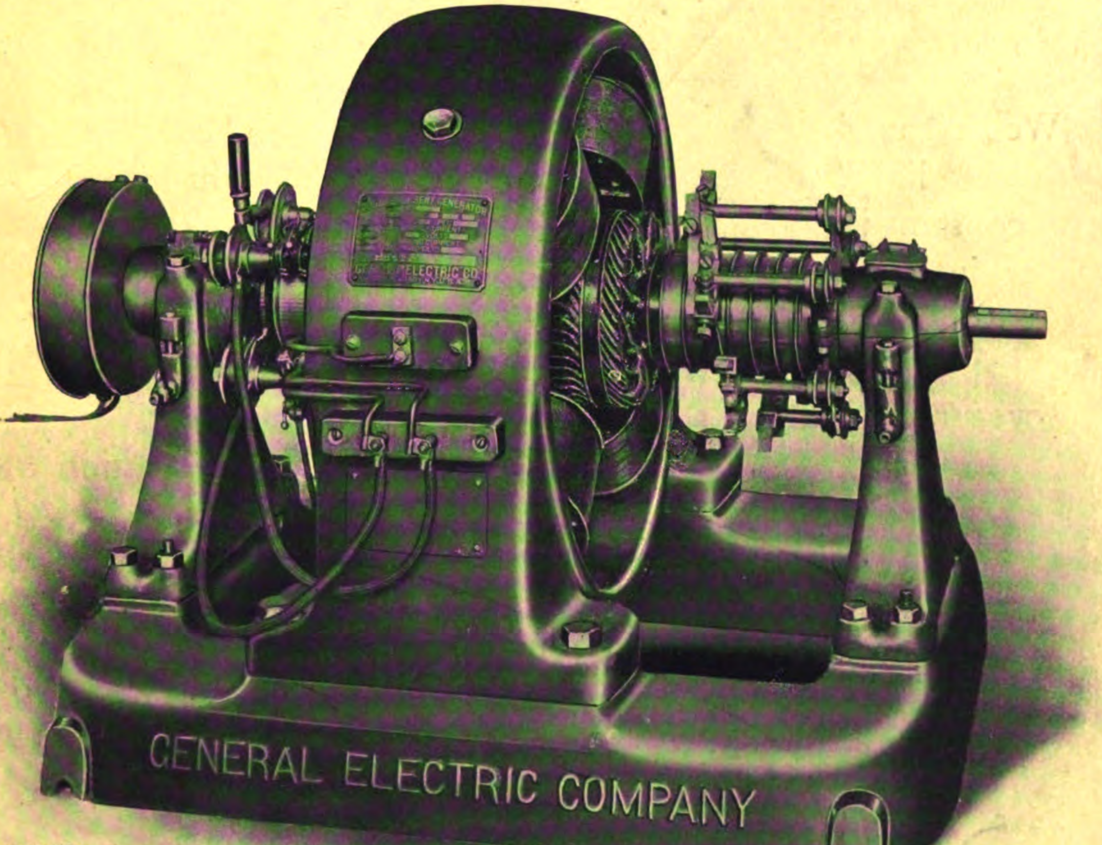
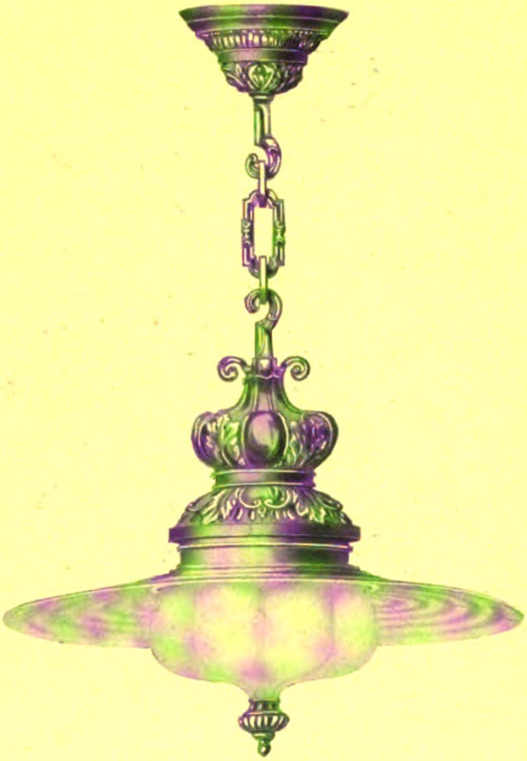

GENERAL ELECTRIC COMPANY
GENERAL ELECTRIC CO.
GE PUBL'N BUREAU

10 Kw. Double Current Generator
"Testing Outfits for College Laboratories"—Page 64

Ornamental Tungsten Diffusers

Designed for use in public buildings, stores and offices where artistic beauty in lighting fixtures is as important as efficiency and economy

Well diffused light, constant in intensity does not produce eye-strain or fatigue



The light from these Diffusers fills all the requirements of good illumination

The Ornamental Tungsten Diffuser is designed for use with 25, 40, 50 and 100 watt Tungstens in the 5 and 6 light types. The single light type is intended for use with the 100 or 250 watt sizes. The internal construction is the same as in the Tungsten Economy Diffuser. The new features consist of ornamental casings of various designs, and enclosing shades and reflectors of art glass.

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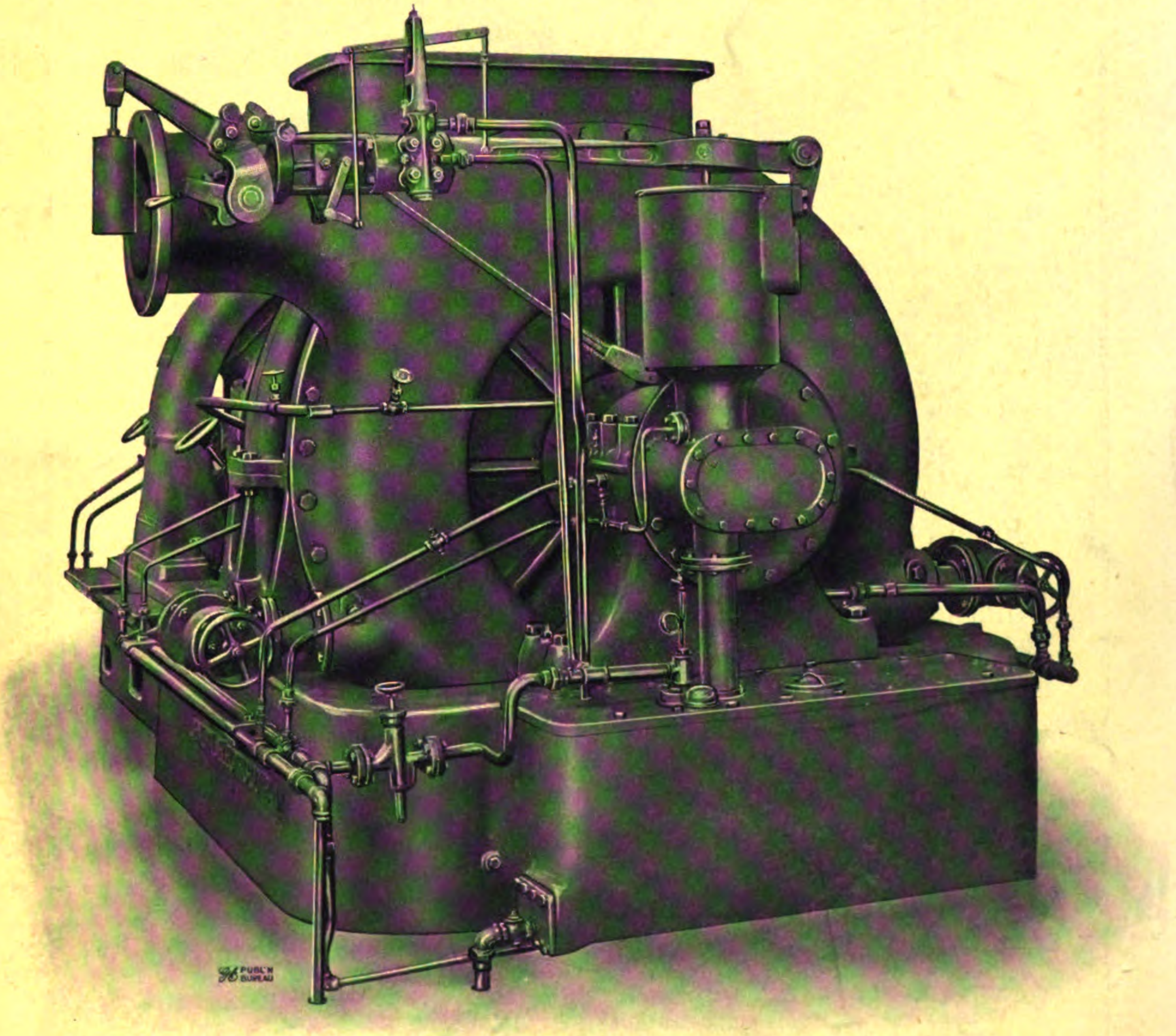
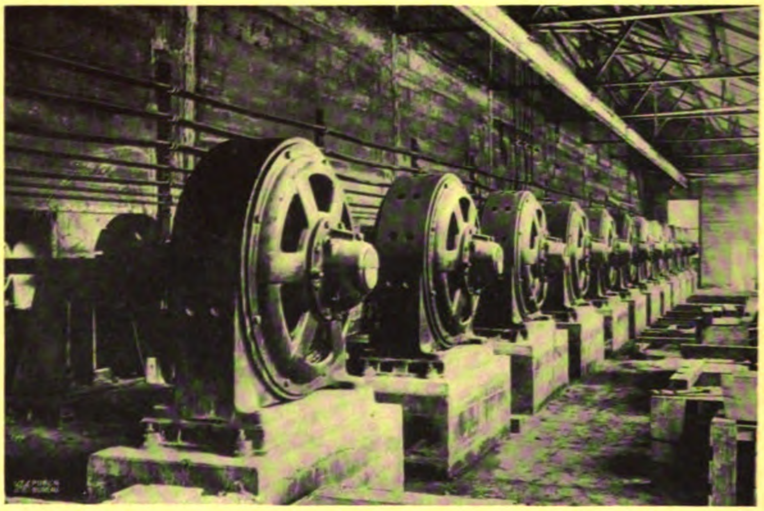


500 Kw. Low Pressure Curtis Turbine
"The Curtis Turbine"—Page 101

Electric Motors for Cement Mills



TWELVE 100 H.P. 166 2-3 R.P.M. INDUCTION MOTORS DRIVING TUBE MILLS IN UNIVERSAL PORTLAND CEMENT CO'S PLANT NO. 4

Each of the twelve motors shown above drives a raw material tube mill through only one gear reduction. This method saves one-half the power which was lost through the old method.

Every motor is working at the highest possible efficiency

These motors are entirely dust proof and will run in an atmosphere filled with cement dust where it would be practically impossible to use engine drive. For especially hard or constant service General Electric Motors are unequalled as they are solidly built in every part and are extremely simple.

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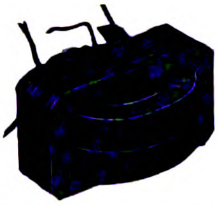
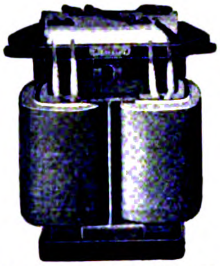
APRIL, 1909

Water and Ice Flowing Over Schaghticoke Dam of the Schenectady Power Company
(See page 149)

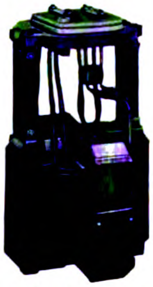
Real Transformer History



Core and coils of one of our early shell type transformers.



Core and coils of Type H transformer. Note cylindrical coils.



Core and coils of Improved Type H transformer. Note cylindrical coils and compact arrangement.

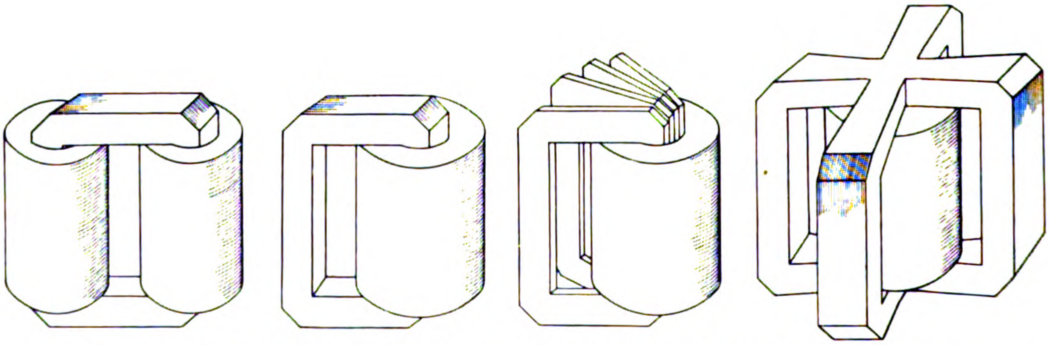
In 1895 the General Electric Company discarded the shell type construction at its highest stage of development and adopted the core type as standard for lighting transformers. The cylindrical coils—possible only with the core type—were found to be ideal for the application of reliable insulation and for efficient radiation and simplicity of arrangement. Hundreds of thousands of these core type—Type H—transformers are to-day in efficient service—positive proof of their merit.

In 1904 the General Electric Company, having brought the original Type H to its highest stage of development, began investigating a distributed core type construction. This design gave a shorter magnetic circuit and a shorter mean length of turn while retaining the good points of the earlier Type H. Two years' investigation resulted in the Improved Type H—now accepted as the standard lighting transformer by discriminating purchasers.

Exterior view of one of our early shell type transformers, 1890

Exterior view of Type H Transformer, 1895

Exterior view of Improved Type H Transformer, 1907.



Elementary diagram showing evolution of Improved Type H Transformer from earlier Type H designs.

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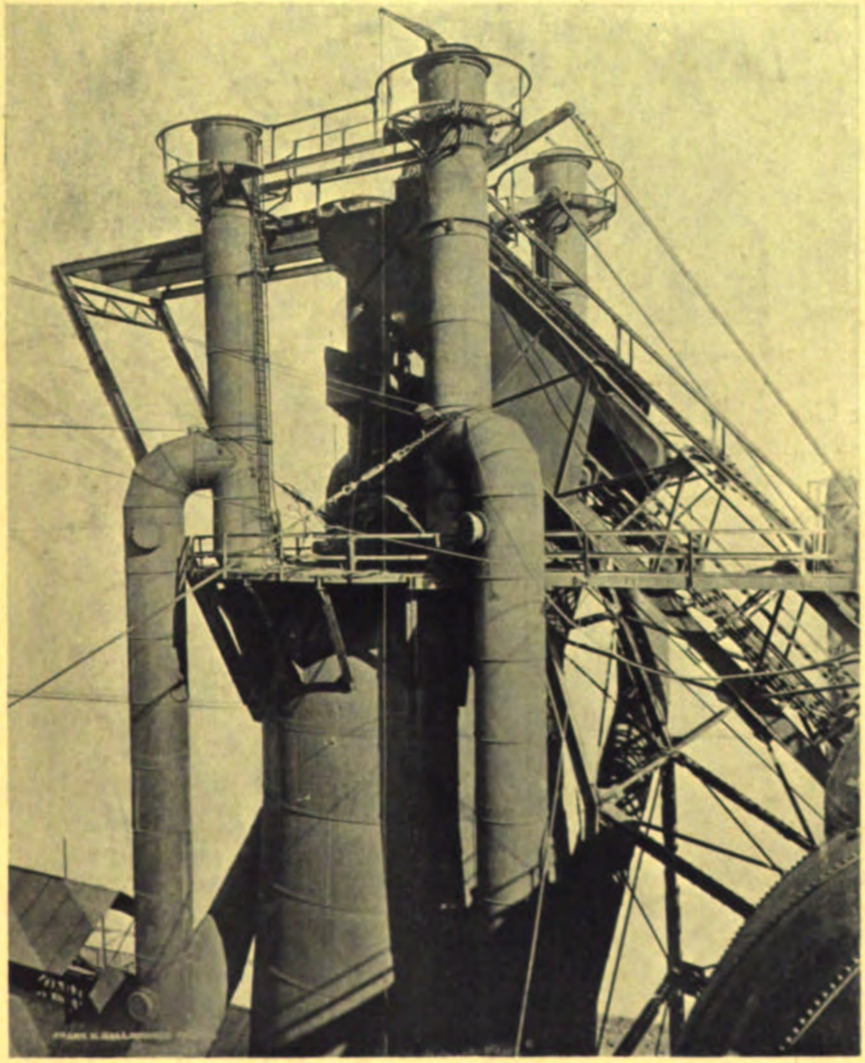

Top of Modern Blast Furnace
"Iron and Steel—Furnace Products"—Page 234

1200-Volt
Direct Current Railway System
"An Unqualified Success"

INDIANAPOLIS SEYMOUR SCOTTSBURG SELLERSBURG JEFFERSONVILLE LOUISVILLE
203
INDIANAPOLIS – LOUISVILLE
203

Two-car train of the Indianapolis and Louisville Traction Company

The General Electric Company is prepared to furnish complete equipments for the generation, transmission, and utilization of 1200-volt direct current on interurban railway systems.

The following roads are in operation with General Electric 1200-volt apparatus

	No. Cars	Mileage
Central California Traction Company	6	16
Indianapolis and Louisville Traction Company	10	46
Indianapolis, Columbus and Southern Traction Company	3	41
Pittsburg, Harmony, Butler and Newcastle Railway	12	64

General Electric 1200-volt apparatus has been ordered by the following roads

	No. Cars	Mileage
Southern Pacific Railroad (Alameda Branch)	44	35
Milwaukee Electric Railway and Light Company	30	90
Briantea Electric Railway (Italy)	3	16
Bresciana Electric Railway (Italy)	8	33

Our Railway Department will be pleased to answer inquiries and prepare estimates

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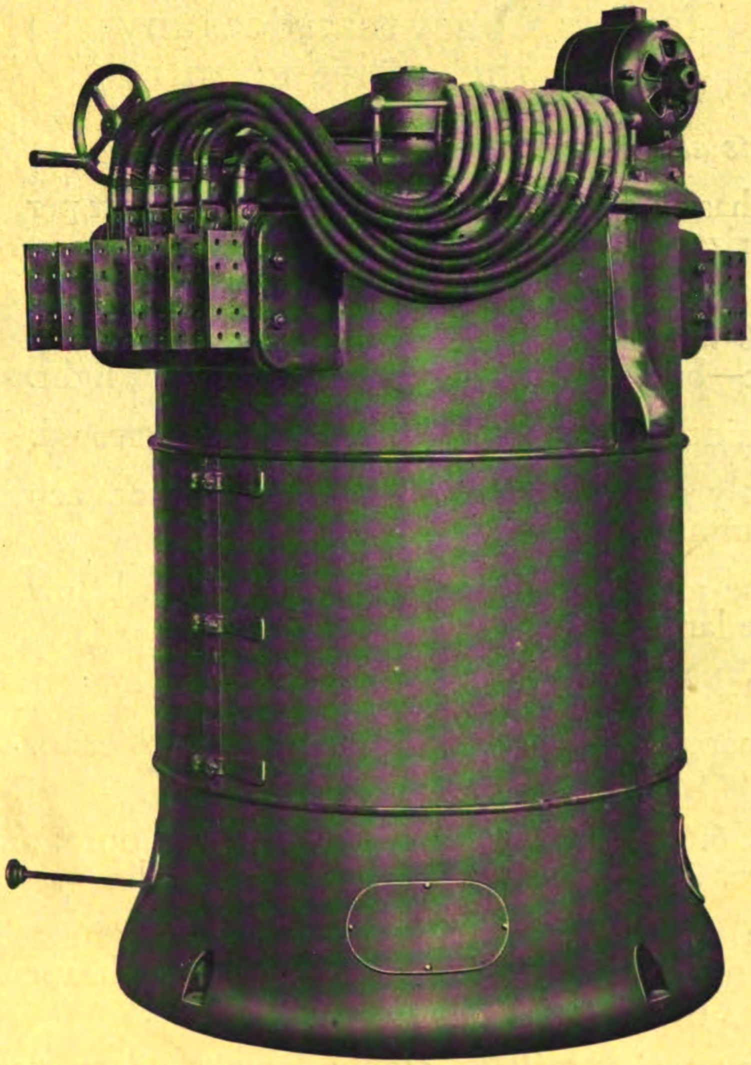

280 Kw. Six-Phase Air Blast Induction Regulator for Rotary Converter

(See Page 263)

The New 6.6-Ampere Magnetite Arc Lamp

For direct current series circuits

Officially adopted by the City of Boston—3500 of them

> "And Boston gets more light
> for less money than does any
> city in the entire country"

Some facts about the lamp—

It has an efficiency of *three-tenths* of a watt per horizontal candle-power.

It consumes practically the same power as the 500-watt direct or alternating current enclosed arc—but gives two to three times as much light.

Maintenance costs are only slightly increased.

Only one electrode must be renewed at each trimming.

The arc is steady—no heavy shadows below the lamp.

Enclosing globes are not required.

Operates equally well from series rectifiers or Brush arc machines.

The new 6.6 ampere lamp is very similar to our 4 ampere lamp, over 35,000 of which are now installed.

We wish you to thoroughly investigate this new lamp. There is no doubt that it gives the best and cheapest illumination of any lamp in commercial service.

Full information will be gladly forwarded on request.

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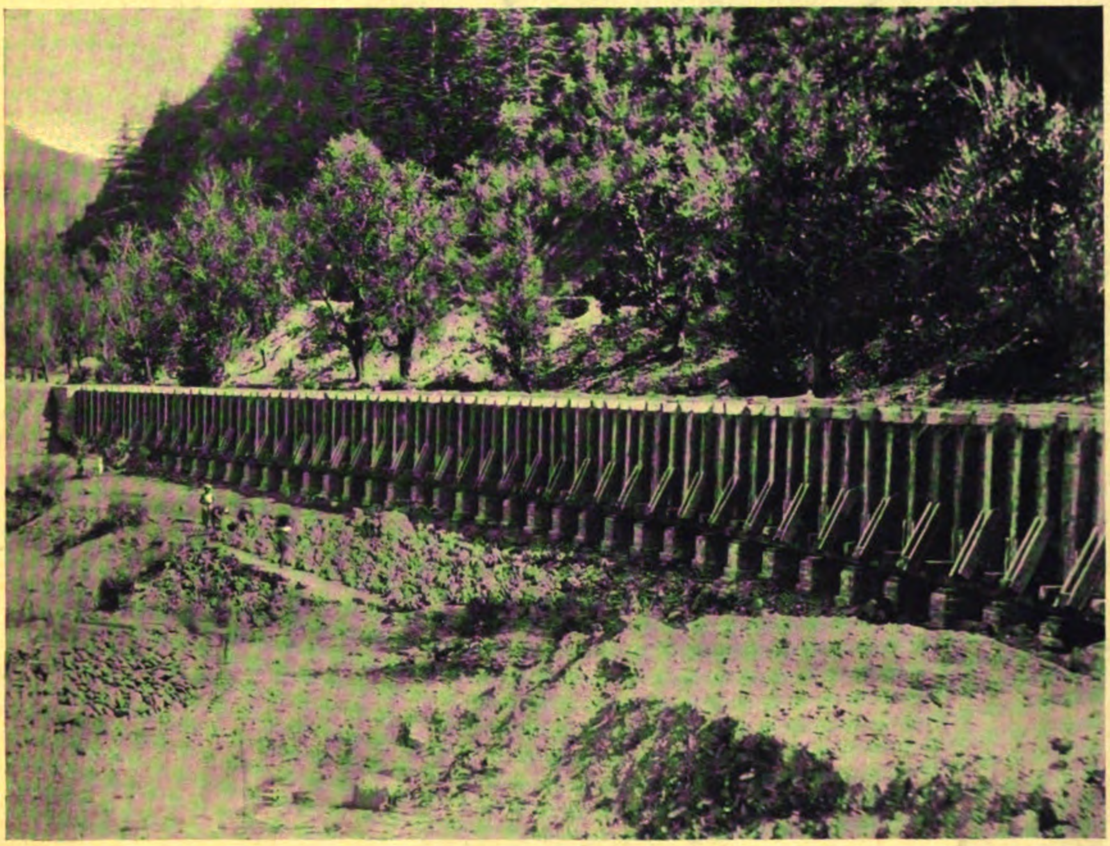

Section of Flume

Jhelum Power Installation, India—See Page 293

G-I Flame Arc Lamps

17-HOUR LAMP

For lighting large areas, the flame arc lamp is more efficient than any other illuminant. The superior properties of the light make this lamp of exceptional value for lighting foundries, machine shops, etc., where the conditions call for a light having penetrating qualities. The brilliant, golden yellow light of the flame arc lamp closely approximating sunlight, is particularly effective in a foggy or smoky atmosphere. The G-I flame arc lamp is strongly constructed, its mechanism reliable and durable, and it is easily and quickly trimmed.

Points of Superiority of the G-I Flame Arc Lamp

Rigid and strong in construction.

Simple and efficient operation.

Positive feed.

Indestructible magnets.

Mechanism chamber not sealed.

Insulation of non-inflammable material.

Every part accessible when shell is lowered to the trimming position.

Every iron or steel part heavily galvanized.

90% of parts interchangeable.

A lamp for your lamp man—not your meter man.

Made for operation on any commercial circuit, either A.C. or D.C., singly or in series.

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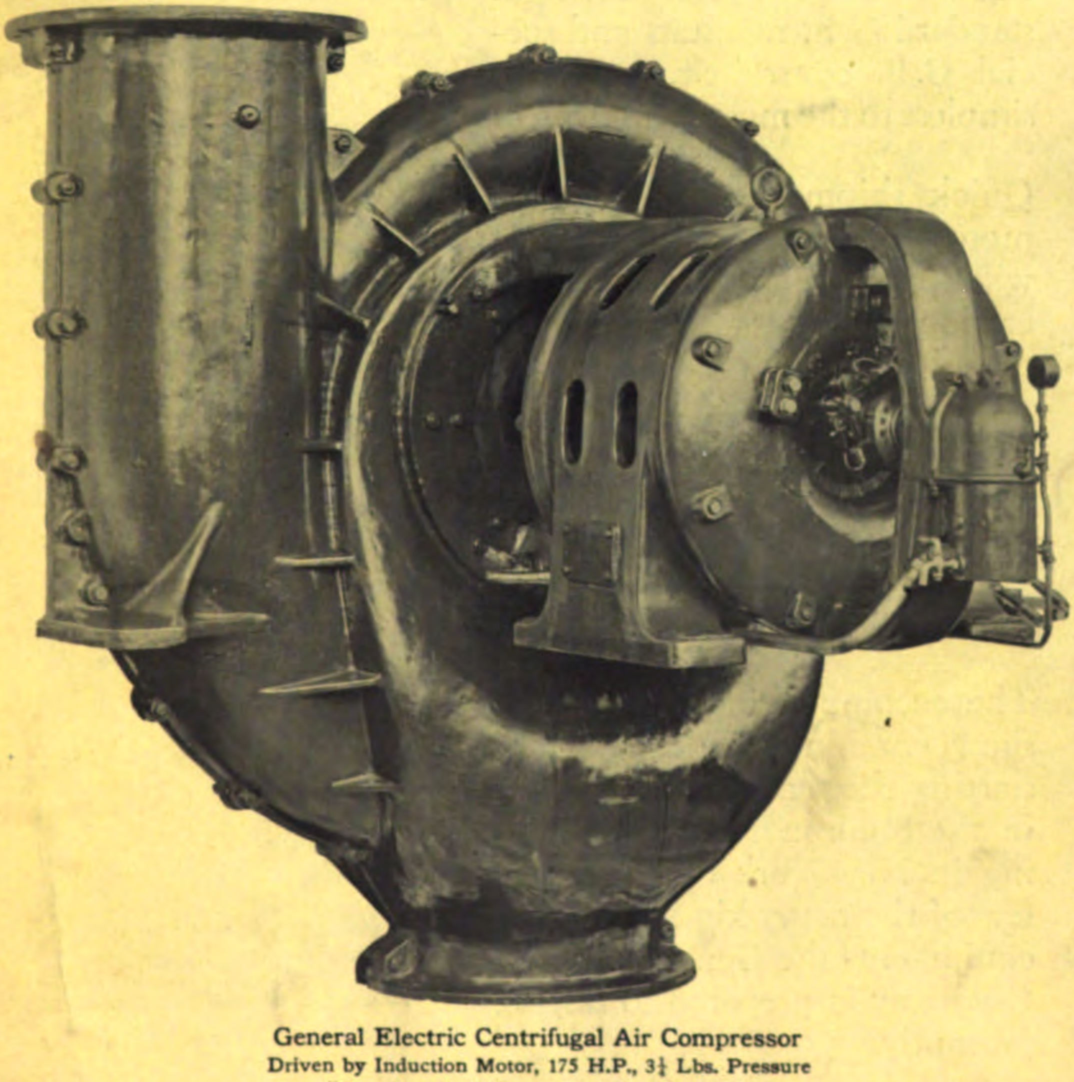


General Electric Centrifugal Air Compressor
Driven by Induction Motor, 175 H.P., $3\frac{1}{2}$ Lbs. Pressure
"Centrifugal Air Compressors"—Page 372

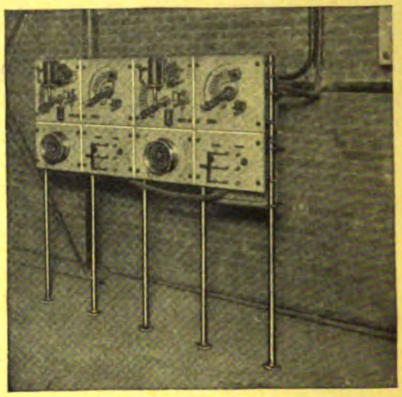
Apparatus for Motor Control

Modern manufacturing facilities are combined with experienced engineering ability in the production of complete lines of standard G. E. rheostats and special G. E. controllers, from the simplest to the most complicated.

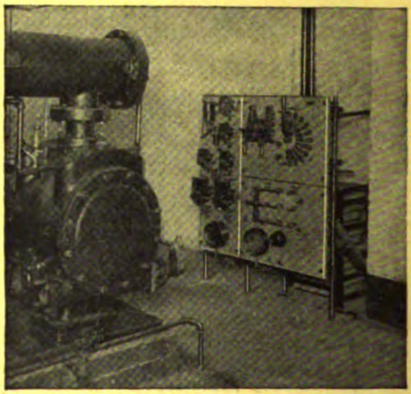
Quick shipments are made of motor controlling apparatus that will stand the test of severe operation and show great reserve capacity.

Prompt service in furnishing expert engineering advice is one of the features offered to purchasers of G. E. motor-controlling equipment.

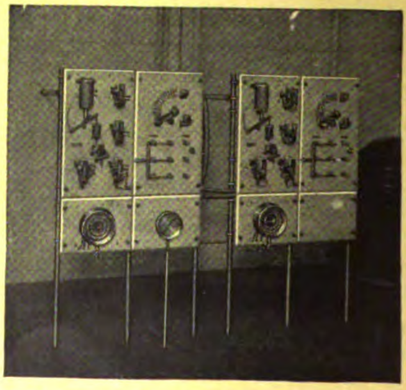
The accompanying illustrations show combined hand- and self-starting rheostat panels, installed in the Hudson Terminal Building in New York City — only a few of the many kinds of special equipments the General Electric Company is prepared to furnish promptly.



Combined hand- and self-starting panels with field control on hand-starting side.



Combined hand- and self-starting panels for 85-100 h.p. motor, driving air compressor.



Combined hand- and self-starting panels for 30 h.p. motors.

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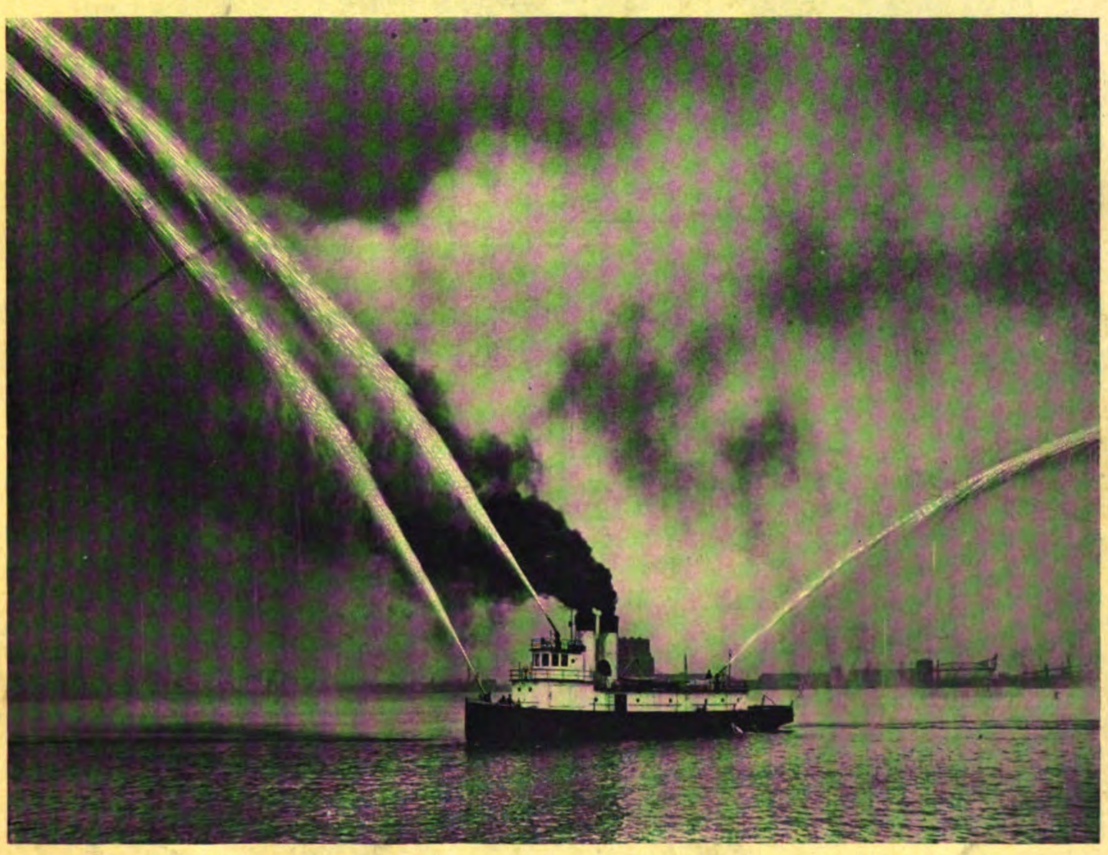

The Duluth Fireboat "McGonagle" in Action, Throwing Streams from the Three Main Turret Nozzles.

"Duluth and San Francisco Fireboats."—Page 420

Luminous Arc Lamps

Two thousand of the new 6.6 ampere Luminous (Magnetite) Arc Lamps are being installed in Boston streets.

Some facts which influenced the City of Boston in its selection:

The City secures two to three times the light obtained with the old arc-lighting system at practically the same cost.

The arc is steady—no heavy shadows beneath the lamp.

The light is white and of an attractive appearance.

Some facts which influenced the Boston Edison Co. in its selection:

The lamp can be used to replace 6.6 ampere enclosed arcs without a change in station equipment.

The maintenance costs are only slightly increased.

Only one electrode must be renewed at each trimming.

Enclosing globes are not required.

"And Boston gets more light for less money than any city in the country."

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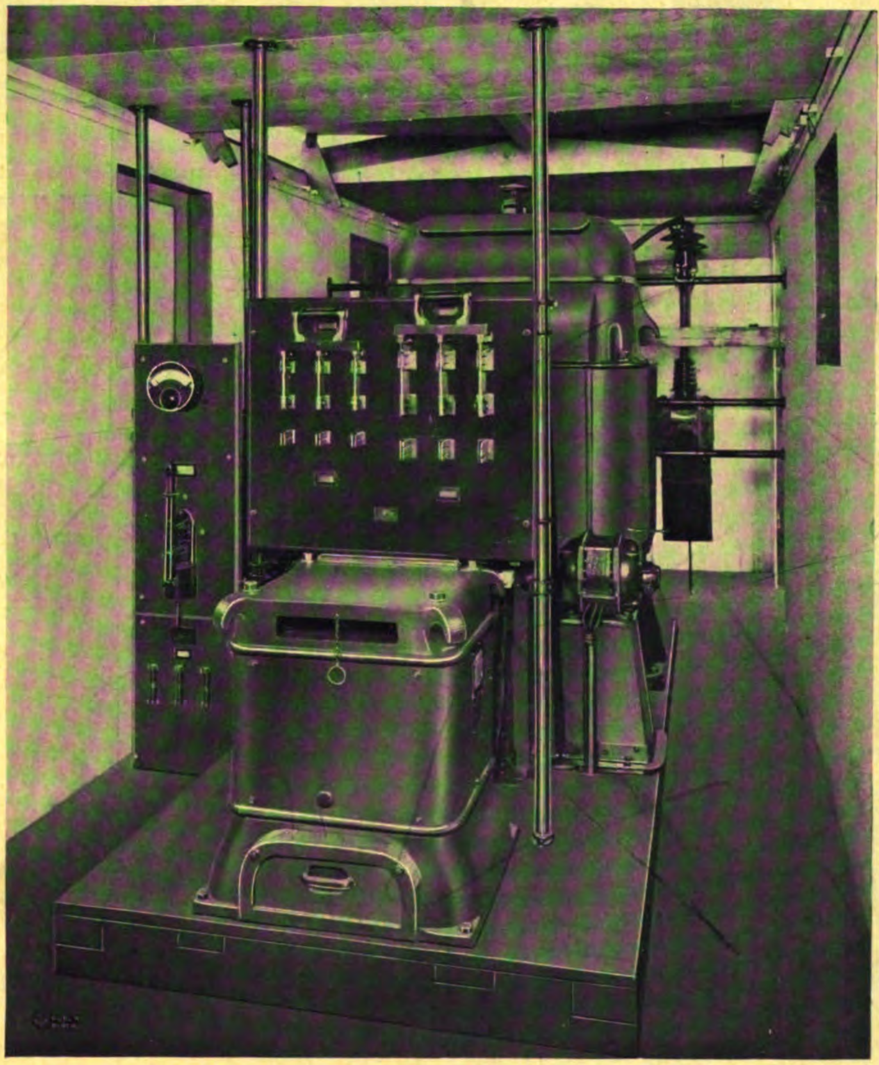
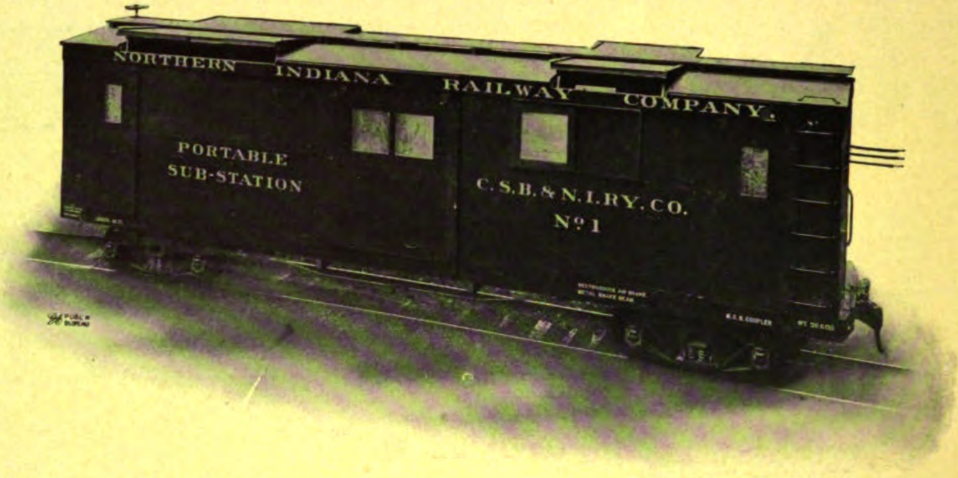
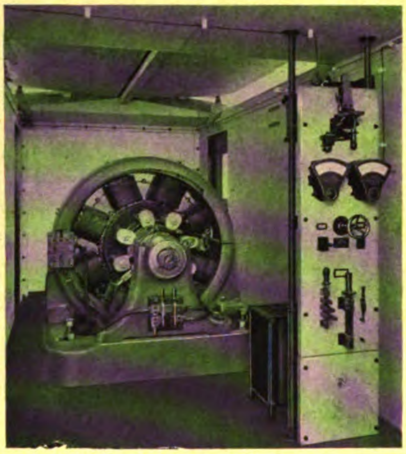


Transformer End of Portable Substation
Chicago, South Bend & Northern Indiana Railway Co.

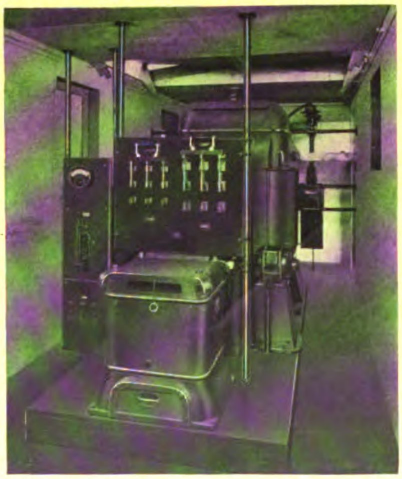
(See Page 468)



300 KW. 25,000-VOLT PORTABLE SUBSTATION



PORTABLE SUBSTATION (ROTARY END)



PORTABLE SUBSTATION (TRANSFORMER END)

A means of power conversion for use at short notice at any point of the railway system

Portable Substations

General Electric Portable Substations are desirable adjuncts to any railway:

For insuring continuity of power supply, in case of accident to any substation, with minimum investment in permanent substations.

For saving large investment in copper and substation equipment on lines heavily loaded on special days or seasons only.

For providing additional power at any point where the traffic may be temporarily abnormally heavy.

For furnishing power to new lines or extensions while under construction.

Built in any capacity up to 500 kw. and for any transmission voltage up to 60,000 volts—with either rotary converters or motor generator sets.

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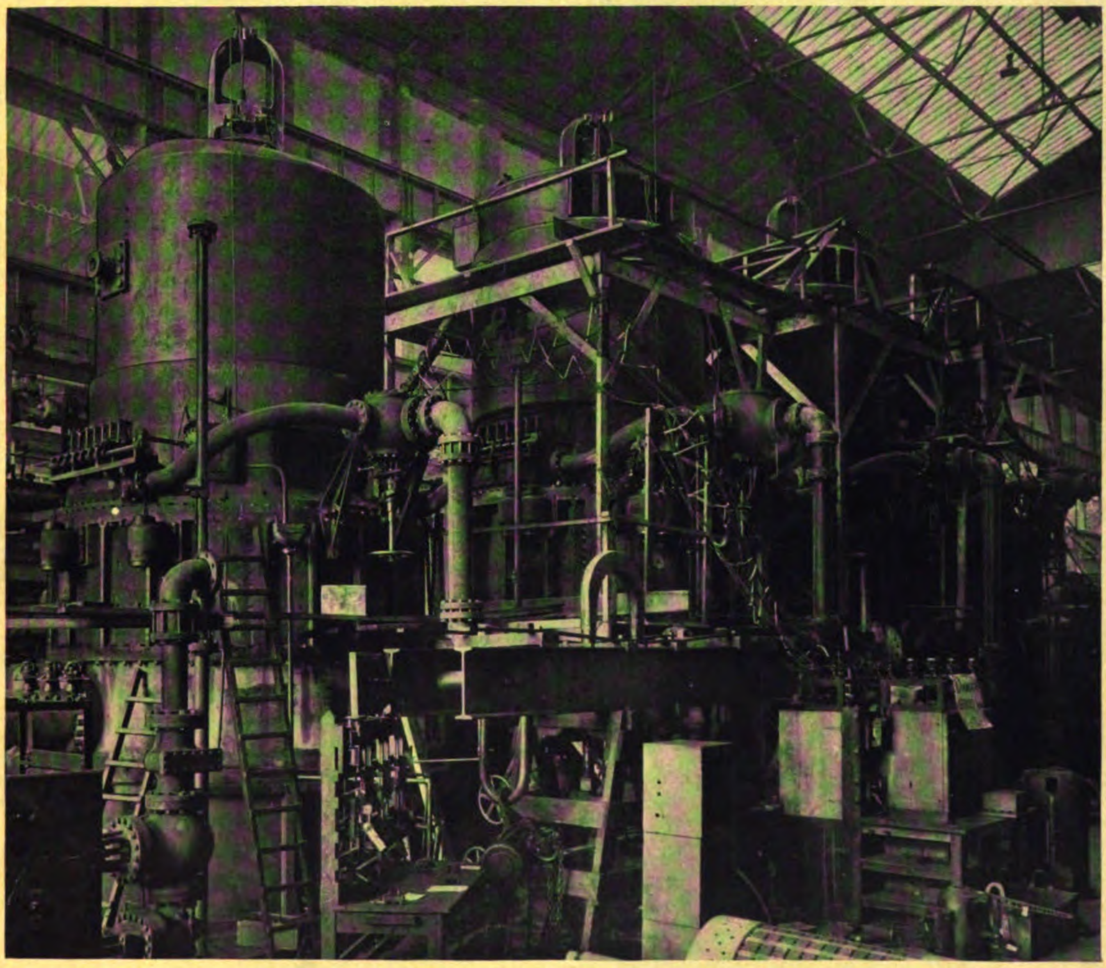
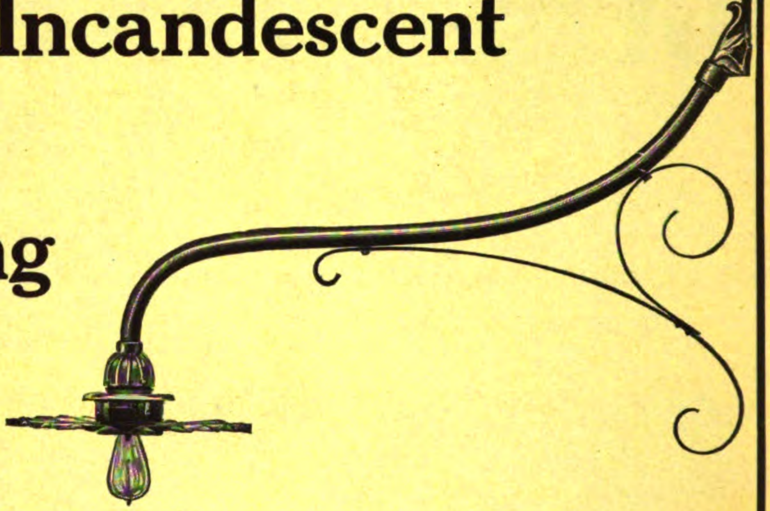


View in Turbine Testing Department of General Electric Company—One 8000 Kw., One 6000 Kw. and Two 5000 Kw. Curtis Turbines

("Commercial Electrical Testing"—page 485)

Series Incandescent Street Lighting



The fixture illustrated above is one of several designs now being placed on the market by the General Electric Company. It has many points of superiority over former designs in that it embodies features not found in any other types:

It is made up of few parts.
Can be furnished for open or concealed wiring.
Arm is made of 1 1-4 in. pipe.
The Insulator and Receptacle are a unit.
The Insulator forms a support for the Reflector.

Central Station men will find this fixture an improvement over other types as repair part item is reduced to a minimum.

In addition to the above the General Electric Company is the pioneer in the manufacture of Constant Current Transformers and Panel Boards for the complete system.

2265

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DECEMBER, 1909

Momentary Short Circuit on Direct Current Generator without Commutating Poles; a Special Test
("Commercial Electrical Testing"—Page 533)

Intensified Arc Lamps

Provide Ideal Illumination of Large Interiors at Minimum Cost

Illumination .	Even distribution of light especially adapts the Intensified Arc Lamp to indoor use. Color of light is almost a perfect white.
Efficiency . . .	1 1/4 watts per mean lower hemispherical candle-power.
Maintenance	Maintenance cost reduced to a minimum. Carbon life is 75 to 100 hours.
Operation . . .	Exceedingly steady and noiseless. Flickering is eliminated.
Design	Entirely new, neat and attractive.

2260

Multiple Unit Control System

Automatic control of trains provided by the Sprague-General Electric Type "M" Multiple Unit System improves railway service in many ways:

Life of equipment is increased by limiting the amount of current taken by the motors.

The most efficient acceleration is assured.

Uniform acceleration results in maximum comfort to passengers.

Motormen can concentrate their attention on the track ahead.

The apparatus illustrated represents the latest developments in the automatic form of Type "M" Control.

MASTER CONTROLLER

Exclusive Features of G.E. Multiple Unit Control

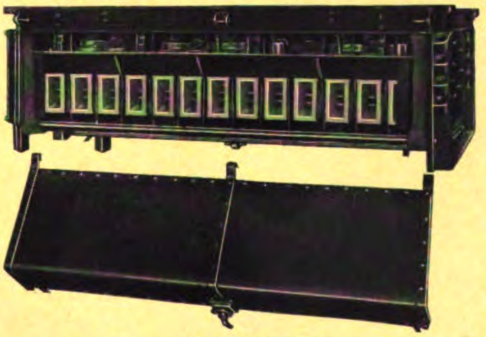
Two Pick-Up Circuits from double relay insure positive automatic operation over wide range of voltage.

Line Current Operation of Contactors provides operating voltage high enough to break down any dirt or oil films on the control contacts. Slight accumulations of dirt do not therefore affect the operation of the control. . . . .

Magnetic Operation of Contactors causes a quick make and break of motor circuits, preventing excessive arcs and resultant burning.

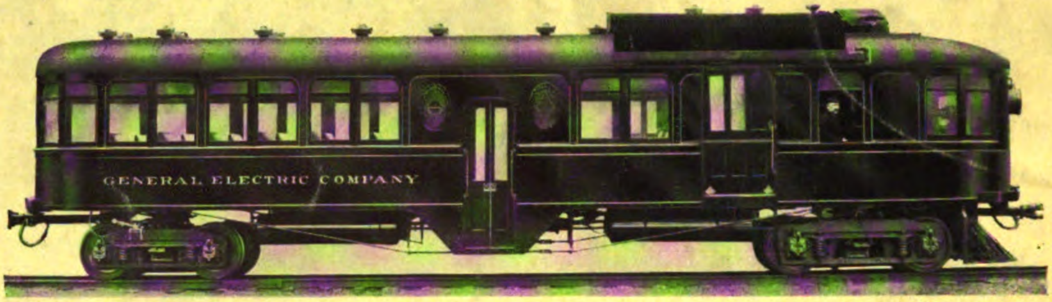
Reduced Liability of Motor Arc Over results from reversing fields instead of armatures, by keeping positive lead always connected to same brush. Reverser can be used for braking without chance of damage.

DOUBLE PICK-UP CURRENT LIMIT RELAY



CONTACTORS IN BOX

Over 6000 Type "M" Equipments have been sold to about 200 different railways in all parts of the world. Many of these roads have duplicated their orders several times — conclusive evidence that the control has proved successful.



GAS-ELECTRIC CAR FOR PASSENGER AND BAGGAGE SERVICE—45 PASSENGERS

Gas-Electric Car

The Ideal Car for Branch Line Service

The flexibility of operation, economy and absolute reliability of the General Electric Gas-Electric Car have been amply demonstrated.

Gasolene engine is located entirely above the floor line, and is independent of the truck, which is equipped with standard railway motors of 200 h.p. capacity.

Control is simple and similar to that of a trolley car.

Car is electrically lighted, avoiding fire risk. +-4-

It operates at high speed, accelerates rapidly, and is entirely free from all objectionable noise, vibration and odor.

The equipment is adapted to various styles of car body, estimates on which we are prepared to furnish.

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